frame of reference for his system of values. This task he has always avoided by resorting to god as an absolute source of truth, or to self-delusion through reason, which can be used to justify anything by confusing the frames of reference and arguing in one domain with relations valid in another. The ultimate truth on which a man bases his rational conduct is necessarily subordinated to his personal experience and appears as an act of choice expressing a preference that cannot be transferred rationally; accordingly, the alternative to reason, as a source for a universal system of values, is aesthetic seduction in favor of a frame of reference specifically designed to comply with his desires (and not his needs) and defining the functions to be satisfied by the world (cultural and material) in which he wants to live.

AUTOPOIESIS

The Organization of the Living

1973

by

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and

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PREFACE

This small book is very large: it contains the living universe. It is a privilege to be asked to write this preface, and a delight to do so. That is because I recognize here a really important book, both in general and specifically. Before talking about the specific contents at all, I would like to explain why this is in general so.

IN GENERAL

We are the inheritors of categorized knowledge; therefore we inherit also a world view that consists of parts strung together, rather than of wholes regarded through different sets of filters. Historically, synthesis seems to have been too much for the human mind – where pratical affairs were concerned. The descent of the synthetic method from Plato through Augustine took men's perception into literature, art and mysticism. The modern world of science and technology is bred from Aristotle and Aquinas by analysis. The categorization that took hold of medieval scholasticism has really lasted it out. We may see with hindsight that the historic revolts against the scholastics did not shake free from the shackles of their reductionism.

The revolt of the rationalists – Descartes, Spinoza, Leibniz – began from a principle of 'methodical doubt'. But they became lost in mechanism, dualism, more and more categorization; and they ended in denying relation altogether. But relation is the stuff of system. Relation is the essence of synthesis. The revolt of the empiricists – Locke, Berkeley, Hume – began from the nature of understanding about the environment. But analysis was still the method, and categorization still the practical tool of advance. In the bizarre outcome, whereby it was the empiricists who denied the very existence of the empirical world, relation survived – but only through the concept of mental association between mental events. The system 'out there', which we call nature, had been annihilated in the process.

By the time Kant was devoting his prodigious mind to sorting all this out, the battle was lost. If the, quoting him, unconscious understanding organizes sensory experience into schemata, while conscious understanding organizes it into categories, the notion of identity remains for Kant forever transcendental.

Now the individual has vanished, in practical terms; as to the assemblage of individuals called society, that too has vanished into a transcendental construct. We have no need to legislate through any consensus of actual people, but only to meet needs that *might* have arisen from the noumenal will.

And what of science itself? Science is ordered knowledge. It began with classification. From Galen in the second century through to Linnaeus in the eighteenth, analysis and categorization provided the natural instrumentality of scientific progress. Ally this fact with the background of philosophical thought, and the scene is set for the inexorable development of the world view that is so difficult to challenge today. It is a world view in which real systems are annihilated in trying to understand them, in which relations are lost because they are not categorized, in which synthesis is relegated to poetry and mysticism, in which identity is a political inference. We may inspect the result in the structure and organization of the contemporary university.

It is an iron maiden, in whose secure embrace scholarship is trapped. For many, this is an entirely satisfactory situation, just because the embrace *is* secure. A man who can lay claim to knowledge about some categorized bit of the world, however tiny, which is greater than anyone else's knowledge of that bit, is safe for life: reputation grows, paranoia deepens. The number of papers increases exponentially, knowledge grows by infinitesimals, but understanding of the world actually recedes, because the world really is an interacting system. And since the world, in many of its aspects, is changing at an exponential rate, this kind of scholarship, rooted in the historical search of its own sanctified categories, is in large part unavailing to the needs of mankind.

There has been some recognition of this, and inter-disciplinary studies are by now commonplace in every university. But will this deal with the problem? Unfortunately, it will not. We still say that a graduate must have his 'basic discipline', and this he is solemnly taught – as if such a thing had a precise environmental correlate, and as if we know that God knew the difference between physics and chemistry. He learns also the academic *mores*, catches the institutional paranoia, and proceeds to propagate the whole business. Thus it is that an 'interdisciplinary study' often consists of a group of disciplinarians holding hands in a ring for mutual comfort. The ostensible topic has slipped down the hole in the middle. Among those who recognize this too, a natural enough debate has ensued on the subject: can an undergraduate be taught 'interdisciplinary studies' *as* his basic subject? But there is no such subject; there is no agreement on what it would be like; and we are rather short of anyone qualified to do the teaching. Those who resist the whole idea, in my view correctly, say that it would endanger the norms of good scholarship. There is a deadlock.

Against this background, let us consider *Autopoiesis*, and try to answer the question: 'What is it?' The authors say: "Our purpose is to understand the organization of living systems in relation to their unitary character". If the book deals with living systems, then it must be about biology. If it says anything scientific about organization, it must be about cybernetics. If it can recognize the nature of unitary character, it must be about epistemology – and also (remembering the first author's massive contribution to the understanding of perception) it will be about psychology too. Yes, it is indeed about all these things. Will you then call this an interdisciplinary study in the field of psychocyberbioepistemics? Do so only if you wish to insult the authors. Because *their* topic has *not* slipped down the hole in the middle. Therefore it is not an interdisciplinary study of the kind defined. It is not about analysis, but synthesis. It does not play the Game of the Categories. And it does not interrelate disciplines; it transcends them. If, because of my remarks about Kant, this seems to say that it annihilates them, then we are getting somewhere.

For there resides my belief in the book's general importance. The dissolution of the deadlock within the disciplinary system that I described above has got to be *meta*systemic, not merely interdisciplinary. We are not interested in forming a league of disciplinary paranoids, but (as Hegel could have told us) in a higher synthesis of disciplines. What emerges in this book is not classifiable under the old categories. Therefore it is predictable that no university could contain it, although all universities can and now do contain interdisciplinary institutions – because, in that very word, suitable obeisance is paid to the hallowed categories, and no one cares if the answers slip down the hole in the middle. As to the prediction that universities cannot contain this kind of work, I have often see it fulfilled. In the present case it is falsified, and I offer heartfelt congratulations to the University of Chile.

I say 'heartfelt' for this reason. In the mounting pile of new books printed every year that are properly called scientific, one may take hold of one's candle and search like a veritable Diogenes for a single one answering to the honest criteria I have proposed for a metasystemic utterance. There is only a handful in existence at all, which is not surprising in view of the way both knowledge and academia are organized. And yet, as I have also proposed, herein lies the world's real need. If we are to understand a newer and still evolving world; if we are to educate people to live in that world; if we are to legislate for that world; if we are to abandon categories and institutions that belong to a vanished world, as it is well-nigh desparate that we should; then knowledge must be rewritten. *Autopoiesis* belongs to the new library.

IN PARTICULAR

The authors first of all say that an autopoietic system is a homeostat. We already know what that is: a device for holding a critical systemic variable within physiological limits. They go on to the definitive point: in the case of autopoietic homeostasis, the critical variable is *the system's own organization*. It does not matter, it seems, whether every measurable property of that organizational structure changes utterly in the system's process of continuing adaptation. *It* survives.

This is a very exciting idea to me for two reasons. In the first place it solves the problem of identity which two thousand years of philosophy have succeeded only in further confounding. The search for the 'it' has led farther and farther away from anything that common sense could call reality. The 'it' of scholasticism is a mythological substance in which anything attested by the senses or testable by science inheres as a mere accident – its existence is a matter of faith. The 'it' of rationalism is unrealistically schizophrenic, because it is uncompromising in its duality – extended substance and thinking substance. The 'it' of empiricism is unrealistically insubstantial and ephemeral at the same time – *esse est percipi* is by no means the verdict of any experiencing human being.

The 'it' of Kant is the transcendental 'thing-in-itself' – an untestable inference, an intellectual gewgaw. As to the 'it' of science and technology in the twentieth century world of conspicuous consumption . . . 'it' seems to be no more than the collection of epiphenomena which mark 'it' as consumer or consumed. In this way hardheaded materialism seems to make 'it' as insubstantial as subjective idealism made it at the turn of the seventeenth century. And this, the very latest, the most down-to-earth, interpretation of 'it' the authors explicitly refute.

Their 'it' is notified precisely by its survival in a real world. You cannot find it by analysis, because its categories may all have changed since you last looked. There is no need to postulate a mystical something which ensures the preservation of identity *despite* appearances. The very continuation is 'it'. At least, that is my understanding of the authors' thesis – and I note with some glee that this means that Bishop Berkeley got the precisely right argument

precisely wrong. He contended that something not being observed goes out of existence. Autopoiesis says that something that exists may turn out to be unrecognizable when you next observe it. This brings us back to reality, for that is surely true.

The second reason why the concept of autopoiesis excites me so much is that it involves the destruction of teleology. When this notion is fully worked out and debated, I suspect it will prove to be as important in the history of the philosophy of science as was David Hume's attack on causality. Hume considered that causation is a mental construct projected onto changing events which have, as we would say today, associated probabilities of mutual occurrence. I myself have for a long time been convinced that purpose is a mental construct imported by the observer to explain what is really an equilibrial phenomenon of polystable systems. The arguments in Chapter II appear to me to justify this view completely, and I leave the reader to engender his own excitement in the discovery of a 'purposelessness' that nonetheless makes good sense to a human being – just because he is allowed to keep his identity, which alone *is* his 'purpose'. It is enough.

But that salute to the authors is also self-congratulation, and I turn quickly aside. If a book is important, if at any time and from any source *information* is received, then something is changed – not merely confirmed. There are two arguments in this book that have changed me, and one of them effected its change after a profound inward struggle. Perhaps this part of the Preface should be printed as an epilogue: if I am not saying enough to be understood in advance of the reading, then I am sorry. It is too much to hope that the reader will return.

People who work with systems-theoretic concepts have often drawn attention to the subjective nature of 'the system'. A system is not something presented to the observer, it is something recognized by him. One of the consequences of this is that the labelling of connections between the system and its environment as either inputs or outputs is a process of arbitrary distinction. This is not very satisfatory. For example, a motor car in action is evidently a system. Suppose that it is recognized as 'a system for going from *A* to *B*'; then the water in the radiator is evidently an input, and displacement is evidently an output. Now consider the following scenario. Two men approach a motor car, and push it towards a second motor car. They then connect the batteries of the two cars with a pair of leads, and the engine of the first car fires. They disconnect the leads, and run the engine hard in neutral gear. We can guess what they are doing; but how is the objective scientist going to describe that system? Displacement is evidently an input, and one output is the rise in temperature of the water in the radiator. In case my example sounds too transparent, note that Aristotle thought that the brain was a 'human radiator', namely an apparatus for cooling the blood. Note also that he was right.

The fact is that we need a theoretical framework for any empirical investigation. This is the *raison d'être* of epistemology, and the authors make that point. In the trivial example I have just given, we need to know 'all about motor cars' before we can make sense of the empirical data. But it often happens in science that we know nothing at all about our 'motor cars', and sit there scratching our heads over data that relate to we know not what. There is a prime example of this in current scientific work, which is so embarrasssing that scientists in general pretend that it is not there. I am referring to the whole field of parapsychology – to the mass of data which seems to say: precognition, telepathy, telekinesis *exist*. But we flounder among statistical artifacts, and lack the theoretical framework for interpretation. This is made clear in the very name of ESP – 'extrasensory perception' which, if one thinks about it, constitutes an internal contradiction of terms.

Autopoiesis as a concept propounds a theoretical framework within which to cope with the confusion that arises from the subjective recognition of 'the system' and the arbitrary classification of its inputs and outputs. For the authors explain how we may treat autopoietic systems as if they were not autopoietic (that is, they are allopoietic) when the boundaries of the system are enlarged. Moreover, autopoietic systems may have allopoietic components. These ideas are immensely helpful, because our recognition of the circumstances in which a system should be regarded as either auto- or allo-poietic enables us to define 'the system' in an appropriate context. That is to say that the context is the recursion of systems within which the system we study is embedded, instead of being the cloud of statistical epiphenomena generated by our attempt to study it.

Understanding this changed me. The second change involved the intellectual struggle I mentioned earlier, and it concerns the authors' views on the information flowing within a viable system. In the numbered Paragraph (iv) of Section I of Chapter III they say: 'The notion of coding is a cognitive notion which represents the interactions of the observer, not a phenomenon operative in the physical domain. The same applies to the notion of regulation'. On first reading, this seemed to me plainly wrong. In the numbered Paragraph (v) of Section 3 of Chapter IV they say: "Notions such as coding, message or information are not applicable to the phenomenon of self-reproduction". Wrong again, I considered; indeed, outrageous – especially when

taken with this remark from the first sentence of Section 3: 'reproduction . . . cannot enter as a defining feature of the organization of living systems'. Finally, in the numbered Paragraph (ii) of Section 3 of Chapter V, the authors say; 'A linguistic domain . . . is intrinsically non-informative'. Surely that is finally absurd?

All of this is totally alien to what we (most of us working in cybernetics) have believed. Information, including codes and messages and mappings, was indeed for us the whole story of the viable system. If one thinks of reproduction, for example, as the process of passing on a DNA code from an aging set of tissues to an embryonic set of tissues, then the survival of the code itself is what matters. The tissues of each generation are subject to aging and finally death, but the code is transmitted. The individual becomes insignificant, because the species is in the code. And that is why identity vanishes in an ageless computer program of bits – a program that specifies the hydrogen-bonded base pairs that link the sugar-phosphate backbones of the DNA molecule.

The whole outlook turns out to be wrong, and the book must speak for itself on this score. But it is an extraordinarily condensed book, which is why this preface is inordinately long. I do not know whether the authors' arguments about information led me to understand their concept of autopoiesis, or *vice versa*. What I am now sure about is that they are right. Nature is not about codes: we observers invent the codes in order to codify what nature is about. These discoveries are very profound.

What is less profound but equally important is the political consequence of this crisis about identity. The subordination of the individual to the species cannot be supported. "*Biology cannot be used any more to justify the dispensability of the individual for the benefit of the species, society or mankind, under the pretense that its role is to perpetuate them.*" After that, the world is a different place.

IN CONTENTION

The authors know it, and they draw the immediate inference. It is to say that scientists can no longer claim to be outside the social milieu within which they operate, invoking objectivity and disinterest; and in truth we have known this, or ought to have known it, ever since Hiroshima. But again this book gives us the theoretical basis for a view that might otherwise shroud something fundamental in a cloak of mere prudence. "No position or view that has any relevance in the domain of human relations can be deemed free from ethical and political implications, nor can a scientist consider himself alien to these implications". However, the authors go on to say that they do not fully agree between themselves on the questions this poses from the vantage point of their own work on autopoiesis – and they refuse to discuss them further (numbered Paragraph (iv) of Section 2 of Chapter V).

This seems to be because they do not resolve the question (posed a little earlier) whether human societies are or are not themselves biological systems. At this point, then, I ask to be relieved of the tasks of comment and interpretation; I ask for permission actively to enter this arena of discussion – where the angels fear to tread. For I am quite sure of the answer: yes, human societies *are* biological systems. Moreover, I claim that this book conclusively proves the point. This is a delicate matter, because presumably at least one of the originators of autopoietic theory disagrees, or is less than sure . . . Nonetheless, I have read the book many times; and one of those readings was exclusively devoted to validating this contention against the authors' own criteria of autopoiesis at every point.

The outcome, to which I was admittedly predisposed because of my own work, says that any cohesive social institution is an autopoietic system – because it survives, because its method of survival answers the autopoietic criteria, and because it may well change its entire appearance and its apparent purpose in the process. As examples I list: firms and industries, schools and universities, clinics and hospitals, professional bodies, departments of state, and whole countries.

If this view is valid, it has extremely important consequences. In the first place it means that every social institution (in several of which any one individual is embedded at the intersect) is embedded in a larger social institution, and so on recursively – and that all of them are autopoietic. This immediately explains why the process of change at any level of recursion (from the individual to the state) is not only difficult to accomplish but actually impossible – in the full sense of the intention: 'I am going completely to change myself'. The reason is that the 'I', that self-contained autopoietic 'it', is a *component* of another autopoietic system. Now we already know that the first can be considered as allopoietic with respect to the second, and that is what makes the second a viable autopoietic system. But this is in turn means that the larger system perceives the embedded system as diminished – as less than fully autopoietic. That perception will be an illusion; but it does have consequences for the contained system. For now its own autopoiesis must respond to a special kind of constraint: treatment which attempts to deny its own autopoiesis.

Consider this argument at whatever level of recursion you please. An individual attempting to reform his own life within an autopoietic family cannot fully be his new self because the family insists that he is actually his old self. A country attempting to become a socialist state cannot fully become socialist; because there exists an international autopoietic capitalism in which it is embedded, by which the revolutionary country is deemed allopoietic. These conclusions derive from entailments of premises which the authors have placed in our hands. I think they are most valuable.

Then let me try to answer the obvious question: why do not the authors follow this line of development themselves, and write the second half of the book (as I hope they eventually will) – which would be about the nature and adaptation of social institutions, and the evolution of society itself? Well, to quote their sentence again: "Our purpose is to understand the organization of living systems in relation to their unitary character". This formulation of the problem begs the question as to what is allowed to be a called a living system as they themselves admit. "Unless one knows which is the living organization one cannot know which organization is living". They quickly reach the conclusion however (Subsection (b) of Section 2 of Chapter 1) that "*autopoiesis is necessary and sufficient to characterize the organization of living systems*". Then they display some unease, quoting the popular belief: ". . . and no synthetic system is accepted as living".

The fact is that if a social institution is autopoiétic (and many seem to answer to the proper criteria) then, on the authors' own showing, it is necessarily alive. That certainly sounds odd, but it cannot be helped. It seems to me that the authors are holding at arms length their own tremendously important discovery. It does not matter about this mere word 'alive'; what does matter is that the social institution has *identity* in the biological sense: it is not just the random assemblage of interested parties that it is thought to be.

When it comes to social evolution then, when it comes to political change: we are not dealing with institutions and societies that will be different tomorrow because of the legislation we passed today. The legislation – even the revolution – with which we confront them does not alter them at all; it proposes a new challenge to their autopoietic adaptation. The behavior they exhibit may have to be very different if they are to survive: the point is that they have not lost their identities.

The interesting consequence is, however, that the way an autopoietic system will respond to a gross environmental challenge is highly predictable – *once the nature of its autopoiesis is understood*. Clever politicians intuit those adaptations; and they can be helped by good scientists using systems-theoretic models. Stupid politicians do not understand why social institutions do not lose their identities overnight when they are presented with perfectly logical reasons why they should; and these are helped by bad scientists who devote their effort to developing that irrelevant logic.

In an era when rapid institutional change is a prerequisite of peaceful survival in the face of every kind of exponentially rising threat, it seems to me that the architects of change are making the same mistake all over the world. It is that they perceive the system at their own level of recursion to be autopoietic, which is because they identify themselves with that system and know themselves to be so; but they insist on treating the systems their system contains, and those within which their system is contained, as allopoietic. This is allowable in terms of scientific description, when the input and output surfaces are correctly defined. Nonetheless it is politically blind to react towards the container and contained systems in a way which makes such a model evident, because at these other levels of recursion the relevant systems perceive themselves as autopoietic too.

This statement seems to be worth making. I could not have made it so succinctly without the language developed in this book. I could not have formulated it at all without the new concepts that Humberto Maturana and Francisco Varela have taught me. I thank them both very much, on behalf of everyone.

STAFFORD BEER

So long as ideas of the nature of living things remain vague and ill-defined, it is clearly impossible, as a rule, to distinguish between an adaptation of the organism to the environment and a case of fitness of the environment for life, in the very most general sense. Evidently to answer such questions we must possess clear and precise ideas and definitions of living things. Life must by arbitrary process of logic be changed from the varying thing which it is into an independent variable or an invariant, shorn of many of its most interesting qualities to be sure, but no longer inviting fallacy through our inability to perceive clearly the questions involved.

Henderson, *The Fitness of the Environment*

AUTOPOIESIS

The Organization of the Living

INTRODUCTION

A universe comes into being when a space is severed into two. A unity is defined. The description, invention and manipulation of unities is at the base of all scientific inquiry.

In our common experience we encounter living systems as unities that appear to us as autonomous entities of bewildering diversity endowed with the capacity to reproduce. In these encounters autonomy apears so obviously an essential feature of living systems that whenever something is observed that seems to have it, the naive approach is to deem it alive. Yet, autonomy, although continuously revealed in the self-asserting capacity of living systems to maintain their identity through the active compensation of deformations, seems so far to be the most elusive of their properties.

Autonomy and diversity, the maintenance of identity and the origin of variation in the mode in which this identity is maintained, are the basic challenges presented by the phenomenology of living systems to which men have for centuries addressed their curiosity about life.

In the search for an understanding of autonomy classic thought, dominated by Aristotle, created vitalism by endowing living systems with a non-material purposeful driving component that attained expression through the realization of their forms. After Aristotle, and as variations of his fundamental notions, the history of biology records many theories which attempt in one way or another to encompass all the phenomenology of living systems under some peculiar organizing force. However, the more biologists looked for the explicit formulation of one or other of these special organizing forces, the more they were disappointed by finding only what they could find anywhere else in the physical world: molecules, potentials and blind material interactions governed by aimless physical laws. Thence, under the pressure of unavoidable experience and the definite thrust of Cartesian thought a different outlook emerged, and mechanicism gradually gained the biological world by insisting that the only factors operating in the organization of living systems were physical factors, and that no non-matieral vital organizing force was necessary. In fact, it seems now apparent that any biological phenomenon, once properly defined, can be described as arising from the interplay of physicochemical processes whose relations are specified by the context of its definition.

Diversity has been removed as a source of bewilderment in the understanding of the phenomenology of living systems by Darwinian thought and particulate genetics which have succeeded in providing an explanation for it and its origin without resorting to any peculiar directing force. Yet, the influence of these notions through their explanation of evolutionary change, has gone beyond the mere accounting for diversity: it has shifted completely the emphasis in the evaluation of the biological phenomenology from the individual to the species, from the unity to the origin of its parts, from the present organization of living systems to their ancestral determination.

Today the two streams of thought represented by the physicochemical and the evolutionary explanations, are braided together. The molecular analysis seems to allow for the understanding of reproduction and variation, the evolutionary analysis seems to account for how these processes might have come into being. Apparently we are at a point in the history of biology where the basic difficulties have been removed. Biologists, however, are uncomfortable when they look at the phenomenology of living systems as a whole. Many manifest this discomfort by refusing to say what a living system is. Others attempt to encompass present ideas under comprehensive theories governed by organizing notions, like cybernetic principles, that require from the biologists the very understanding that they want to provide. The ever present question is: 'What is common to all living systems that we qualify

them as living'; if not a vital force, if not an organizing principle of some kind, what then? To take only a notable recent example let us mention J. Monod's book *Le hasard et la necessitè*. He tries to answer this question but, following the emphasis of evolutionary thought, he postulates a teleonomic organization of molecular nature and the subordination of the organization of the individual to a plan defined by the species, in which the invariance of reproduction is determinant. Yet, teleonomic and evolutionary notions leave the question of the nature of the organization of the living unity essentially untouched.

Our endeavor is to disclose the nature of the living organization. However, in our approach we make a starting point of the unitary character of a living system, and maintain that the evolutionary thought through its emphasis on diversity, reproduction and the species in order to explain the dynamics of change has obscured the necessity of looking at the autonomous nature of living unities for the understanding of the biological phenomenology. Also we think that the maintenance of identity and the invariance of defining relations in the living unities are at the base of all possible ontogenic and evolutionary transformation in biological systems, and this we intend to explore. Thus, our purpose is: to understand the organization of living systems in relation to their unitary character.

Our approach will be mechanistic: no forces or principles will be adduced which are not found in the physical universe. Yet, our problem is the living organization and therefore our interest will not be in properties of components, but in processes and relations between processes realized through components. This is to be clearly understood. An explanation is always a reformulation of a phenomenon showing how its components generate it through their interactions and relations. Furthermore, an explanation is always given by us as observers, and it is central to distinguish in it what pertains to the system as constitutive of its phenomenology from what pertains to our domain of description, and hence to our interactions with it, its components and the context in which it is observed. Since our descriptive domain arises because we simultaneously behold the unity and its interactions in the domain of observation, notions arising in the domain of description do not pertain to the constitutive organization of the unity (phenomenon) to be explained. Furthermore, an explanation may take different forms according to the nature of the phenomenon explained. Thus, to explain the movement of a falling body one resorts to properties of matter, and to laws that describe the conduct of material bodies according to these properties (kinetic and gravitational laws), while to explain the organization of a control plant one resorts to relations and laws that describe the conduct of relations. In the first case, the elements used in the explanation are bodies and their properties; in the second case, they are relations and their relations, independently of the nature of the bodies that satisfy them. As in this latter case, in our explanation of the organization of living systems, we shall be dealing with the relations which the actual physical components must satisfy to constitute one, not with the identification of these components. It is our assumption that there is an organization that is common to all living systems, whichever the nature of their components. Since our subject is this organization, not the particular ways in which it may be realized, we shall not make distinctions between classes or types of living systems.

This mode of thinking is not new, and is explicitly related to the very name of mechanicism. We maintain that living systems are machines and by doing this we point at several notions which should be made explicit. First, we imply a non-animistic view which it should be unnecessary to discuss any further. Second, we are emphasizing that a living system is defined by its organization and, hence, that it can be explained as any organization is explained, that is, in terms of relations, not of component properties. Finally, we are pointing out from the start the dynamism apparent in living systems and which the word 'machine' connotes.

We are asking, then, a fundamental question: 'What is the organization of living systems, what kind of machines are they, and how is their phenomenology, including reproduction and evolution, determined by their unitary organization?'

ON MACHINES, LIVING AND OTHERWISE

1. MACHINES

Machines are usually viewed as concrete hardware systems, defined by the nature of their components and by the purpose that they fulfill in their operations as man-made artifacts. This view however is obviously naive because it says nothing about how they are constituted. That machines are unities is apparent; that they are made of components that are characterized by certain properties capable of satisfying certain relations that determine in the unity the interactions and transformations of these same components is also apparent. What is not so apparent is that the actual nature of the components, and the particular properties that these may possess other than those participating in the interactions and transformations which constitute the system, are irrelevant and can be any. In fact, the significant properties of the components must be taken in terms of relations, as the network of interactions and transformations into which they can enter in the working of the machine which they integrate and constitute as a unity.

The relations that define a machine as a unity, and determine the dynamics of interactions and transformations which it may undergo as such a unity, constitute the *organization* of the machine. The actual relations which hold among the components which integrate a concrete machine in a given space, constitute its *structure*. The organization of a machine (or system) does not specify the properties of the components which realize the machine as a concrete system, it only specifies the relations which these must generate to constitute the machine or system as a unity. Therefore, the organization of a machine is independent of the properties of its components which can be any, and a given machine can be realized in many different manners by many different kinds of components. In other words, although a given machine can be realized by many different structures, for it to constitute a concrete entity in a given space its actual components must be defined in that space, and have the properties which allow them to generate the relations which define it.

The use to which a machine can be put by man is not a feature of the organization of the machine, but of the domain in which the machine operates, and belongs to our description of the machine in a context wider than the machine itself. This is a significant notion. Man made machines are all made with some purpose, practical or not, but with some aim (even if it is only to amuse) that man specifies. This aim usually appears expressed in the product of the operation of the machine, but not necessarily so. However, we use the notion of purpose when talking of machines because it calls into play the imagination of the listener and reduces the explanatory task in the effort of conveying to him the organization of a particular machine. In other words, with the notion of purpose we induce the listener to invent the machine we are talking about. This, however, should not lead us to believe that purpose, or aim, or function, are constitutive properties of the machine which we describe with them; such notions are intrinsic to the domain of observation, and cannot be used to characterize any particular type of machine organization. The product of the operations of a machine, however, can be used to this end in a non-trivial manner in the domain of descriptions generated by the observer.

2. LIVING MACHINES

That living systems are machines cannot be shown by pointing to their components. Rather, one must show their organization in a manner such that the way in which all their peculiar properties arise, becomes obvious. In order to do this, we shall first characterize the kind of machines that living systems are, and then show how the peculiar properties of living systems may arise as consequences of the organization of this kind of machines.

a. *Autopoietic machines*

There are machines which maintain constant, or within a limited range of values, some of their variables. The way this is expressed in the organization of these machines must be such as to define the process as occurring completely within the boundaries of the machine which the very same organization specifies. Such machines are homeostatic machines and all feedback is internal to them. If one says that there is a machine M, in which there is a feedback loop through the environment so that the effects of its output affect its input, one is in fact talking about a larger machine M' which includes the environment and the feedback loop in its defining organization.

Autopoietic machines are homeostatic machines. Their peculiarity, however, does not lie in this but in the fundamental variable which they maintain constant. *An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which*: (i) *through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and* (ii) *constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network*. It follows that an autopoietic machine continuously generates and specifies its own organization through its operation as a system of production of its own components, and does this in an endless turnover of components under conditions of continuous perturbations and compensation of perturbations. Therefore, an autopoietic machine is an homeostatic (or rather a relations-static) system which has its own organization (defining network of relations) as the fundamental variable which it maintains constant. This is to be clearly understood. Every unity has an organization specifiable in terms of static or dynamic relations between elements, processes, or both. Among these possible cases, autopoietic machines are unities whose organization is defined by a particular network of processes (relations) of production of components, the autopoietic network, not by the components themselves or their static relations. Since the relations of production of components are given only as processes, if the processes stop, the relations of production vanish; as a result, for a machine to be autopoietic, its defining relations of production must be continuously regenerated by the components which they produce. Furthermore, the network of processes which constitute an autopoietic machine is a unitary system in the space of the components that it produces and which generate the network through their interactions. The autopoietic network of processes, then, differentiates autopoietic machines from any other kind of unit. In fact: (i) in a man-made machine in the physical space, say a car, there is an organization given in terms of a concatenation of processes, yet, these processes are not processes of production of the components which specify the car as a unity since the components of a car are produced by other processes which are independent of the organization of the car and its operation. Machines of this kind are non-autopoietic dynamic systems. (ii) In a natural physical unity like a crystal, the spatial relations among the components specify a lattice organization which defines it as a member of a class (a crystal of a particular kind), while the kinds of components which constitute it specify it as a particular case in that class. Thus, the organization of a crystal is specified by the spatial relations which define the relative position of its components, while these specify its unity in the space in which they exist – the physical space. This is not so with an autopoietic machine. In fact, although we find spatial relations among its components whenever we actually or conceptually freeze it for an observation, the observed spatial relations do not (and cannot) define it as autopoietic. This is so because the spatial relations between the components of an autopoietic machine are specified by the network of processes of production of components which constitute its organization and they are therefore necessarily in continuous change. A crystal organization then, lies in a different domain than the autopoietic organization: a domain of relations between components, not of relations between processes of production of components; a domain of processes, not of concatenation of processes. We normally acknowledge this by saying that crystals are static.

It is important to realize that we are not using the term organization in the definition of an autopoietic machine in a mystical or transcendental sense, pretending that it has any explanatory value of its own. We are using it only to refer to the specific relations that define an autopoietic system. Thus, autopoietic organization simply means processes interlaced in the specific form of a network of productions of components which realizing the network that produced them constitute it as a unity. It is for this reason that we can say that every time that this organization is actually realized as a concrete system in a given space, the domain of the deformations which this system can withstand without loss of identity while maintaining constant its organization, is the domain of changes in which it exists as a unity. It is thus clear that the fact that autopoietic systems are homeostatic systems which have their own organization as the variable that they maintain constant, is a necessary consequence of the autopoietic organization.

The consequences of this autopoietic organization are paramount:

(i) Autopoietic machines are autonomous; that is, they subordinate all changes to the maintenance of their own organization, independently of how profoundly they may otherwise be transformed in the process. Other machines, henceforth called allopoietic machines, have as the product of their functioning something different from themselves (as in the car example). Since the changes that allopoietic machines may suffer without losing their definitory organization are necessarily subordinated to the production of something different from themselves, they are not autonomous.

(ii) Autopoietic machines have individuality; that is, by keeping their organization as an invariant through its continuous production they actively maintain an identity which is independent of their interactions with an observer. Allopoietic machines have an identity that depends on the observer

and is not determined through their operation, because its product is different from themselves; allopoietic machines do not have individuality.

(iii) Autopoietic machines are unities because, and only because, of their specific autopoietic organization: their operations specify their own boundaries in the processes of self-production. This is not the case with an allopoietic machine whose boundaries are defined by the observer, who by specifying its input and output surfaces, specifies what pertains to it in its operations.

(iv) Autopoietic machines do not have inputs or outputs. They can be perturbated by independent events and undergo internal structural changes which compensate these perturbations. If the perturbations are repeated, the machine may undergo repeated series of internal changes which may or may not be identical. Whichever series of internal changes takes place, however, they are always subordinated to the maintenance of the machine organization, condition which is definitory of the autopoietic machines. Thus any relation between these changes and the course of perturbations to which we may point to, pertains to the domain in which the machine is observed, but not to its organization. Thus, although an autopoietic machine can be treated as an allopoietic machine, this treatment does not reveal its organization as an autopoietic machine.

An organization may remain constant by being static, by maintaining its components constant, or by maintaining constant certain relations between components otherwise in continuous flow or change. Autopoietic machines are organizations of the latter kind: they maintain constant the relations that define them as autopoietic. The actual way in which such an organization may in fact be implemented in the physical space, that is, the physical structure of the machine, varies according to the nature (properties) of the physical materials which embody it. Therefore there may be many different kinds of autopoietic machines in the physical space (physical autopoietic machines); all of them, however, will be organized in such a manner that any physical interference with their operation outside their domain of compensations will result in their disintegration: that is, in the loss of autopoiesis. It also follows that the actual way in which the autopoietic organization is realized in one of these machines (its structure) determines the particular perturbations it can suffer without disintegration, and hence, the domain of interactions in which it can be observed. These features of the actual concreteness of autopoietic machines embodied in physical systems allow us to talk about particular cases, to put them in our domain of manipulation and description, and hence, to observe them in the context of a domain of interactions which is external to their organization. This has two kinds of fundamental consequence:

(i) We can describe physical autopoietic machines, and also manipulate them, as parts of a larger system that defines the independent events which perturb them. Thus, as noted above, we can view these perturbing independent events as inputs, and the changes of the machine that compensate these perturbations as outputs. To do this, however, amounts to treating an autopoietic machine as an allopoietic one, and to recognize that if the independent perturbing events are regular in their nature and occurrence, an autopoietic machine can in fact, be integrated into a larger system as a component allopoietic machine, without any alteration in its autopoietic organization.

(ii) We can analyze a physical autopoietic machine in its physical parts, and treat all its partial homeostatic and regulatory mechanisms as allopoietic machines (sub-machines) by defining their input and output surfaces. Accordingly, these sub-machines are not necessarily components of an autopoietic machine because the relations that define such a machine need not be those that they generate through the input-output relations that define them.

The fact that we can divide physical autopoietic machines into parts does not reveal the nature of the domain of interactions that they define as concrete entities operating in the physical universe.

b. *Living systems*

If living systems are machines, that they are physical autopoietic machines is trivially obvious: they transform matter into themselves in a manner such that the product of their operation is their own organization. However we deem the converse is also true: a physical system if autopoietic, is living. In other words, we claim that the notion of *autopoiesis is necessary and sufficient to characterize the organization of living systems*. This equivalence may not be apparent for some observers due to several reasons which do not pertain to the domain of the organization of autopoietic machines, but which are proper within the domain of description and evaluation of the observers who adopt such reasons, and lead them to its *a priori* negation. The following are some of these reasons:

(i) Machines are generally viewed as human made artifacts with completely known deterministic properties which make them, at least conceptually, perfectly predictable. Contrariwise, living systems are *a priori* frequently viewed as autonomous, ultimately unpredictable systems, with purposeful behavior similar to ours. If living systems were machines, they could be made by man and, according to the view mentioned above, it seems unbelievable that man could manufacture a living system. This view can be easily disqualified, because it either implies the belief that living systems cannot be understood because they are too complex for our meager intellect and will remain so, or that the principles which generate them are intrinsically unknowable; either implication would have to be accepted *a priori* without proper demonstration. There seems to be an intimate fear that the awe with respect to life and the living would disappear if a living system could be not only reproduced, but designed by man. This is nonsense. The beauty of life is not a gift of its inaccessibility to our understanding.

(ii) To the extent that the nature of the living organization is unknown, it is not possible to recognize when one has at hand, either as a concrete synthetic system or as a description, a system that exhibits it. Unless one knows which is the living organization, one cannot know which organization is living. In practice, it is accepted that plants and animals are living but their characterization as living is done through the enumeration of their properties. Among these, reproduction and evolution appear as determinant, and for many observers the condition of living appears subordinated to the possession of these properties. However, when these properties are incorporated in a concrete or conceptual man-made system, those who do not accept emotionally that the nature of life can be understood, immediately conceive of other properties as relevant, and do not accept any synthetic system as living by continuously specifying new requirements.

(iii) It is very often assumed that observation and experimentation are alone sufficient to reveal the nature of living systems and no theoretical analysis is expected to be necessary and least of all sufficient for a characterization of the living organization. It would be long to state why we depart from this radical empiricism. Let us simply say that we believe that epistemological and historical arguments more than justify the contrary view: every experimentation and observation implies a theoretical perspective, and no experimentation or observation has significance or can be interpreted outside the theoretical framework in which it took place.

Our aim was to propose the characterization of living systems that explains the generation of all the phenomena proper to them. We have done this by pointing at autopoiesis in the physical space as a necessary and sufficient condition for a system to be a living one.

To know that a given aim has been attained, is not always easy. In the case at hand, the only possible indication that we have attained our aim is the reader's agreement that all the phenomenology of living systems, including reproduction and evolution, indeed requires and depends on autopoiesis. The following chapters are devoted to show this.

CHAPTER II

DISPENSABILITY OF TELEONOMY

Teleology and teleonomy are notions employed in discourse, descriptive and explanatory, about living systems, and although it is claimed that they do not necessarily enter as causal elements in their functioning, it is asserted that they are essential definitory features of their organization. Our present aim is to show that in the light of the preceding discussion, these notions are unnecessary for the understanding of the living organization.

1. PURPOSELESSNESS

It is usually maintained that the most remarkable feature of living systems is a purposeful organization, or what is the same, the possession of an internal project or program represented and realized in and through their structural organization. Thus, ontogeny is generally considered as an integrated process of development towards an adult state, through which certain structures are attained that allow the organism to perform certain functions according to the innate project which defines it in relation to the environment. Also, phylogeny is viewed as the history of adaptive transformations through reproductive processes aimed at satisfying the project of the species, with complete subordination of the individual to this end. Furthermore, it is apparent that there are organisms that may even appear capable of specifying some purpose in advance (as the authors of this book) and conduct all their activities towards this attainment (heteropoiesis). This element of apparent purpose or the possession of a project or program in the organization of living systems, which has been called teleonomy without implying any vitalistic connotations, is frequently considered as a necessary, if not as a sufficient, definitory feature for their characterization. Purpose or aims, however, as we saw in the first chapter, are not features of the organization of any machine (allo- or autopoietic); these notions belong to the domain of our discourse about our actions, that is, they belong to the domain of descriptions, and when applied to a machine, or any system independent from us, they reflect our considering the machine or system in some encompassing context. In general, the observer puts the machines either conceptually or concretely to some use, and thus defines a set of circumstances that lead the machine to change, following a certain path of variations in its output. The connection between these outputs, the corresponding inputs, and their relation with the context in which the observer includes them, determine what we call the aim or purpose of the machine; this aim necessarily lies in the domain of the observer that defines the context and establishes the nexuses. Similarly the notion of function arises in the description made by the observer of the components of a machine or system in reference to an encompassing entity, which may be the whole machine or part of it, and whose states constitute the goal that the changes in the components are to bring about. Here again, no matter how direct the causal connections may be between the changes of state of the components and the state which they originate in the total system, the implications in terms of design alluded to by the notion of function are established by the observer and belong exclusively to his domain of description. Accordingly, since the relations implied in the notion of function are not constitutive of the organization of an autopoietic system, they cannot be used to explain its operation.

The organization of a machine, be it autopoietic or allopoietic, only states relations between components and rules for their interactions and transformations, in a manner that specifies the conditions of emergence of the different states of the machine which, then, arise as a necessary outcome whenever such conditions occur. Thus, the notions of purpose and function *have no explanatory value* in the phenomenological domain which they pretend to illuminate, because they do not refer to processes indeed operating in the generation of any of its phenomena. This does not preclude their being adequate for the orientation of the listener towards a given domain of thought. Accordingly, a prediction of a future state of a machine consists only in the accelerated realization in the mind of an observer of its succeeding states, and any reference to an early state to explain a later one in functional or purposeful terms, is an artifice of his description, made in the perspective of his simultaneous mental observation of the two states, that induces in the mind of the listener an abbreviated realization of the machine. Therefore any machine, a part of one or a process that follows a predictable course, can be described by an observer as endowed with a project, a purpose or a function, if properly handled by him with respect to an encompassing context.

Accordingly, if living systems are physical autopoietic machines, teleonomy becomes only an artifice of their description which does not reveal any feature of their organization, but which reveals the consistency in their operation within the domain of observation. Living systems, as physical autopoietic machines, are purposeless systems.

2. INDIVIDUALITY

The elimination of the notion of teleonomy as a defining feature of living systems changes the outlook of the problem completely, and forces us to consider the organization of the individual as the central question for the understanding of the organization of living systems.

In fact, a living system is specified as an individual, as a unitary element of interactions, by its autopoietic organization which determines that any change in it should take place subordinated to its maintenance, and thus sets the boundary conditions that specify what pertains to it and what does not pertain to it in the concreteness of its realization. If the subordination of all changes in a living system to the maintenance of its autopoietic organization did not take place (directly or indirectly), it would lose that aspect of its organization which defines it as a unity, and hence it would disintegrate. Of course it is true for every unity, whichever way it is defined, that the loss of its defining organization results in its disintegration; the peculiarity of living systems, however, is that they disintegrate whenever their autopoietic organization is lost, not that they can disintegrate. As a consequence, all change must occur in each living system without interference with its functioning as a unity in a history of structural change in which the autopoietic organization remains invariant. Thus ontogeny is both an expression of the individuality of living systems and the way through which this individuality is realized. As a process, ontogeny, then, is the expression of the becoming of a system that at each moment is the unity in its fullness, and does not constitute a transit from an incomplete (embryonic) state to a more complete or final one (adult).

The notion of development arises, like the notion of purpose, in the context of observation, and thus belongs to a different domain other than the domain of the autopoietic organization of the living system. Similarly, the conduct of an autopoietic machine that an observer can witness, is the reflection of the paths of changes that it undergoes in the process of maintaining constant its organization through the control of the variables that can be displaced by perturbations, and through the specification in this same process of the values around which these variables are maintained at any moment. Since the autopoietic machine has no inputs or outputs, any correlation between regularly occurring independent events that perturb it, and the state to state transitions that arise from these perturbations, which the observer may pretend to reveal, pertain to the history of the machine in the context of the observation, and not to the operation of its autopoietic organization.

EMBODIMENTS OF AUTOPOIESIS

The assertion that physical autopoietic systems are living systems requires the proof that all the phenomenology of a living system can be either reduced or subordinated to its autopoiesis. This proof, obviously, cannot consist in enumerating all biological phenomena and presenting cases of autopoietic systems that exhibit them; rather it must consist in showing that autopoiesis either constitutes or is necessary and sufficient for the occurrence of all biological phenomena, if the proper non-determinant contingencies are given.

1. DESCRIPTIVE AND CAUSAL NOTIONS

An autopoietic system is defined as a unity by its autopoietic organization. The realization of this organization in a physical system requires components which are defined by their role in the autopoiesis and which can only be described in relation to this. Furthermore these components can only be realized by material elements which can exhibit the necessary properties under the conditions specified by the autopoietic organization, and must be produced in the proper topological relation within this organization, by the particular instance (structural realization) of the autopoietic system that they constitute. Accordingly, an autopoietic organization constitutes a closed domain of relations specified only with respect to the autopoietic organization that these relations constitute, and, thus, it defines a 'space' in which it can be realized as a concrete system; a space whose dimensions are the relations of production of the components that realize it:

(i) Relations of constitution that determine that the components produced constitute the topology in which the autopoiesis is realized.

(ii) Relations of specificity that determine that the components produced be the specific ones defined by their participation in the autopoiesis.

(iii) Relations of order that determine that the concatenation of the components in the relations of specification, constitution and order be the ones specified by the autopoiesis.

How these relations of production are embodied in a physical system of

course depends on the particular way in which the autopoiesis is realized, that is, on the actual structure of their realization. There are, however, certain general notions which apply to any particular concrete autopoietic system that we must mention at the outset:

(i) Although indeed energetic and thermodynamic considerations would necessarily enter in the analysis of how the components are physically constituted, and in the description of their proper ties in a specific domain of interactions, such that they may satisfy the requirements of their participation in an autopoietic system, these considerations do not enter in the characterization of the autopoietic organization. If the components can be materialized, the organization can be realized; the satisfaction of all thermodynamic and energetic relations is implicit. Thus, for example, in the concrete case of the cell, that we shall consider in the next section, energetic relations that make possible certain reactions with the participation of ATP are not constitutive of the autopoietic organization. However, it is constitutive of the structure through which the autopoietic organization is realized, that the molecules which participate in it should have among their properties the property of entering into the interactions which generate the autopoietic processes and, hence, of holding the required energy relations.

(ii) Notions such as specification and order are referential notions; that is, they do not have meaning outside the context in which they are defined. Thus, when we speak about relations of specification we refer to the specification of components in the context of that which defines the system as autopoietic. Any other element of specificity that may enter, however necessary it may be for the factibility [factual characterization] of the components, but which is not defined through the autopoietic organization, we take for granted. Similarly with the notion of order. Relations of order refer to the establishment of processes that secure the presence of the components in the concatenation that results in autopoiesis. No other reference is meant, however conceivable it may be within other perspectives of description.

(iii) An autopoietic organization acquires topological unity by its embodiment in a concrete autopoietic system which retains its identity as long as it remains autopoietic. Furthermore, the space defined by an autopoietic system is self-contained and cannot be described by using dimensions that define another space. When we refer to our interactions with a concrete autopoietic system, however, we project this system upon the space of our manipulations and make a description of this projection. This we can do because we interact with the components of the autopoietic system through the properties of their constituting elements that do not lie in the autopoietic space, and thus, we modify the structure of the autopoietic system by modifying its components. Our description, however, follows the ensuing change of the projection of the autopoietic system in the space of our description, not in the autopoietic space.

(iv) Notions such as coding and transmission of information do not enter in the realization of a concrete autopoietic system because they do not refer to actual processes in it. Thus, the notion of specificity does not imply coding, information or instructions; it only describes certain relations, determined by and dependent on the autopoietic organization, which result in the production of the specific components. The proper dimension is that of relations of specificity. To say that the system or part of it, codes for specificity, is not only a misnomer but also misleading; this is so, because such an expression represents a mapping of a process that occurs in the space of autopoiesis onto a process that occurs in the space of human design (heteropoiesis), and it is not a reformulation of the phenomenon. The notion of coding is a cognitive notion which represents the interactions of the observer, not a phenomenon operative in the observed domain. The same applies to the notion of regulation. This notion is valid in the domain of description of heteropoiesis, and it reflects the simultaneous observation and description made by the designer (or his equivalent) of interdependent transitions of the system that occur in a specified order and at specified speeds. The corresponding dimension in an autopoietic system is that of relations of production of order, but here again only in the context of the autopoiesis and not of any particular state of the system as it would appear projected on our domain of descriptions. The notion of regulation, then, can enter in the description, but does not refer to an actual process in the autopoietic organization.

2. MOLECULAR EMBODIMENTS

That a cell is an autopoietic system is trivially apparent in its life cycle. What is not trivial is how the cell is a molecular embodiment of autopoiesis, as it should be apparent in its analysis in terms of the dimensions of its autopoietic space:

(i) *Production of Constitutive Relations*

Constitutive relations are relations that determine the topology of the autopoietic organization, and hence its physical boundaries. The production of constitutive relations through the production of the components that hold these relations is one of the defining dimensions of an autopoietic system. In the cell such constitutive relations are established through the production of molecules (proteins, lipids, carbohydrates and nucleic acids) which determine the topology of the relations of production in general; that is, molecules which determine the relations of physical neighborhood necessary for the components to hold the relations that define them. The cell defines its physical boundaries through its dimension of production of constitutive relations that specify its topology. There is no specification in the cell of what it is not.

(ii) *Production of Relations of Specifications*

Relations of specifications are relations that determine the identity (properties) of the components of the autopoietic organization, and hence, in the case of the cells, its physical factibility. The establishment of relations of specification through the production of components that can hold these relations is another of the defining dimensions of an autopoietic system. In the cell such relations of specification are produced mainly through the production of nucleic acids and proteins that determine the identity of the relations of production in general. In the cell this is obviously obtained, on the one hand, by relations of specificity between DNA, RNA and proteins, and on the other hand, by relations of specificity between enzymes and substrates. Such production of relations of specification holds only within the topological substrate defined by the production of relations of constitution. There is no production in the cell as an autopoietic system of relations of specification that do not pertain to it.

(iii) *Production of Relations of Order*

Relations of order are those that determine the dynamics of the autopoietic organization by determining the concatenation of the production of relations of constitution, specification and order, and hence its actual realization. The establishment of relations of order through the production of components that realize the production of relations of constitution, specification and order, constitute the third dimension of the autopoietic space. In the cell, relations of order are established mainly by the production of components (metabolites, nucleic acids and proteins) that control the speed of production of relations of constitution, specification and order. Relations of order, thus, conform a network of parallel and sequential relations of constitution, specification and order that constitute the cell as a system in which the relations of production that specify this network as a dynamic physical topological unity, are maintained constant. There is no ordering through the autopoietic organization of the cell of processes that do not belong to it.

If one examines a cell it is apparent that:
DNA participates in the specification of polypeptides, and hence, or proteins, enzymatic and structural, which specifically participate in the production of proteins, nucleic acids, lipids, glucides and metabolites. Metabolites (which include all small molecules, monomers or not, produced in the cell) participate in the determination of the speed of the various processes and reactions that constitute the cell, establishing a network of interrelated speeds in parallel and sequentially interconnected processes, both by gating and by constitutive participation, in a way such that every reaction is a function of the state of the transforming network that they integrate. All processes occur bound to a topology determined by their participation in the processes of production of relations of constitution.

We as observers can project all cellular processes upon a system of three orthogonal coordinates, and legitimately say, as valid in the projection, that specification is mostly produced by nucleic acids, constitution by proteins, and order (regulation) by metabolites. The autopoietic space, however, is curved and closed in the sense that it is entirely specified by itself, and such a projection represents our cognitive relation with it, but does not reproduce it. In it, specification takes place at all points where its organization determines a specific process (protein synthesis, enzymatic action, selective permeability); ordering takes place at all points where two or more processes meet (changes of speed or sequence, allosteric effects, competitive and non-competitive inhibition, facilitation, inactivation, etc.) determined by the structure of the participating components; constitution occurs at all places where the structure of the components determines physical neighborhood relations (membranes, particles, active site in enzymes). What makes this system a unity with identity and individuality is that all the relations of production are coordinated in a system describable as an homeostatic system that has its own unitary character as the variable that it maintains constant through the production of its components. In such a system any deformation at any place is not compensated by bringing the system back to an identical state of its components as it would be described by projecting it upon a three-dimensional Cartesian space; rather it is compensated by keeping its organization constant as defined by the relation of the relations of production of relations of constitution, specification and order which constitutes autopoiesis. In other words, compensation of deformation keeps the autopoietic system in the autopoietic space.

That all the biological features of the cell as a unity are determined by its autopoiesis, is henceforth obvious. In fact, the only thing that defines the cell as a unity (as an individual) is its autopoiesis, and thus the only restriction placed on the existence of the cell is the maintenance of autopoiesis. All the rest – that is, its structure – can vary: relations of topology, specificity and order can vary as long as they constitute a network in an autopoietic space.

3. ORIGIN

The production of relations of constitution, specification and order, are not exclusive to autopoietic systems. They are inherent to unitary interactions in general, and to molecular interactions in particular; they depend on the properties of the units or molecules as expressed in the geometric and energetic relationships which they may adopt. Thus, the geometric properties of the molecules determine the relations of constitution, that is, the topology, the physical neighborhoods or spatial relations in which they may enter. The chemical properties of the molecules determine their possible interactions, and, hence, the relations of specificity which are a dimension orthogonal to relations of constitution. Both together, they determine sequence and concatenation of molecular interactions, that is, relations of order. Accordingly, autopoiesis may arise in a molecular system if the relations of production are concatenated in such a way that they produce components that specify the system as a unity which exists only while it is actively produced by such concatenation of processes. This is to say that autopoiesis arises in a molecular system only when the relation that concatenates these relations is produced and maintained constant through the production of the molecular components that constitute the system through this concatenation. Thus, in general, the question of the origin of an autopoietic system is a question about the conditions that must be satisfied for the establishment of an autopoietic space. This problem, then, is not a chemical one, in terms of what molecules took or can take part in the process, but a general one of what relations the molecules or any constitutive units should satisfy. This deserves the following considerations:

(i) An autopoietic system is defined as a unity by and through its autopoietic organization. This unity is, thus, a topological unity in the space in which the components have existence as entities that may interact and have relations. For living systems such a space is the physical space. Without unity in some space an autopoietic system is not different from the background in which it is supposed to lie, and, hence, can only be a system in the space of our description where its unity is conceptually stipulated. Without unity in the physical space a living system would lack the dynamics of production relations which constitute it as a concrete entity in that space.

(ii) The establishment of an autopoietic system cannot be a gradual process; either a system is an autopoietic system or it is not. In fact, its establishment cannot be a gradual process because an autopoietic system is defined as a system; that is, it is defined as a topological unity by its organization. Thus, either a topological unity is formed through its autopoietic organization, and the autopoietic system is there and remains, or there is no topological unity, or a topological unity is formed in a different manner and there is no autopoietic system but there is something else. Accordingly, there are not and there cannot be intermediate systems. We can describe a system and talk about it as if it were a system which, with a little transformation, would become an autopoietic system because we can imagine different systems with which we compare it, but such a system would be intermediate only in our description, and in no organizational sense would it be a transition system.

(iii) Autocatalytic processes do not constitute autopoietic systems because among other things, they do not determine their topology. Their topology is determined by a container that is part of the specification of the system, but which is independent of the operation of the autocatalysis. Processes of this or similar kind are abundant in the physical space. Coupling of independent processes into larger systems is also the rule; these may or may not constitute unities defined by the circumstances of their constitution in a given space, be this space physical or otherwise. They, however, will not constitute or participate in the constitution of an autopoietic system unless the system they conform becomes defined as a topological unity through its embodiment of an autopoietic organization. A unity is defined by an operation of distinction; in an autopoietic system its autopoiesis constitutes the operation of distinction that defines it, and its origin is cocircumstantial with the establishment of this operation.

(iv) The problem of the origin of autopoietic systems has two aspects; one refers to their factibility, and the other to the possibility of their spontaneous occurrence. The first aspect can be stated in the following manner:

the establishment of any system depends on the presence of the components that constitute it, and on the kinds of interactions in which they may enter; thus, given the proper components and the proper concatenation of their interactions, the system is realized. The concrete question about the factibility of a molecular autopoietic system is, then, the question of the conditions in which different chemical processes can be concatenated to form topological unities that constitute relational networks in the autopoietic space. The second aspect can be stated in the following manner: given the factibility of autopoietic systems, and given the existence of terrestrial autopoietic systems, there are natural conditions under which these may be spontaneously generated. Concretely the question would be, 'What were or are the natural conditions under which the components of the autopoietic systems arose or arise spontaneously on the earth, and concatenate to form them?' This question cannot be answered independently of the manner in which the factibility question is answered, particularly in what refers to the factibility of one or several different kinds of molecular autopoietic systems. The presence today of one mode of autopoietic organization on the earth (the nucleic acid protein system), cannot be taken to imply that the factibility question has only one answer.

The notions that we have discussed are valid for the origin (constitution) of autopoietic systems at any level of physical embodiment, molecular or supramolecular. We shall not dwell on the particular circumstances of the establishment of any of these embodiments. We shall leave this matter for another inquiry, accepting the existence of living systems as an existential proof of the factibility of the spontaneous generation of autopoietic systems. We shall consider next the significance of the conditions of topological unity for the diversity of autopoietic systems.

DIVERSITY OF AUTOPOIESIS

Living systems embody the living organization. Living systems are autopoietic systems in the physical space. The diversity of living systems is apparent; it is also apparent that this diversity depends on reproduction and evolution. Yet, reproduction and evolution do not enter into the characterization of the living organization, and living systems are defined as unities by their autopoiesis. This is significant because it makes the phenomenology of living systems dependent on their being autopoietic unities. In fact, reproduction requires the existence of a unity to be reproduced, and it is necessarily secondary to the establishment of such a unity; evolution requires reproduction and the possibility of change, through reproduction of that which evolves, and it is necessarily secondary to the establishment of reproduction. It follows that the proper evaluation of the phenomenology of living systems, including reproduction and evolution, requires their proper evaluation as autopoietic unities.

1. SUBORDINATION TO THE CONDITION OF UNITY

Unity (distinguishability from a background, and, hence, from other unities), is the sole necessary condition for existence in any given domain. In fact, the nature of a unity and the domain in which it exists are specified by the process of its distinction and determination; this is so regardless of whether this process is conceptual (as when a unity is defined by an observer through an operation of distinction in his domain of discourse and description), or whether this process is physical (as when a unity becomes established through the actual working of its defining properties that assert its distinction from a background through their actual operation in the physical space). Accordingly, different kinds of unities necessarily differ in the domain in which they are established, and having different domains of existence they may or may not interact according to whether these domains do or do not intersect. Unity distinction [the distinctiveness and distinguishing of unity], then, is not an abstract notion of purely conceptual validity for descriptive or analytical purposes, but it is an operative notion referring to the process through which a unity becomes asserted or defined: the conditions which specify a

unity determine its phenomenology. In living systems, these conditions are determined by their autopoietic organization. In fact, autopoiesis implies the subordination of all change in the autopoietic system to the maintenance of its autopoietic organization, and since this organization defines it as a unity, it implies total subordination of the phenomenology of the system to the maintenance of its unity. This subordination has the following consequences:

(i) The establishment of a unity defines the domain of its phenomenology, but given the way the unity is constituted by its structure defines the kind of phenomenology that it generates in that domain. It follows that the particular form adopted by the phenomenology of each autopoietic (biological) unity depends on the particular way in which its individual autopoiesis is realized. It also follows that the domain of ontogenic transformations (including conduct) of each individual is the domain of the homeostatic trajectories through which it can maintain its autopoiesis.

(ii) All the biological phenomenology is necessarily determined and realized through individual autopoietic unities in the physical space, and consists of all the paths of transformations that they undergo as homeostatic systems, singly or in groups, in the process of maintaining constant their defining individual relations. Whether in the process of their interactions the autopoietic unities do or do not unite to constitute additional unities, is irrelevant for the subordination of the biological phenomenology to the maintenance of the identity of the individual unities. If united they produce a new unity that is not autopoietic, its phenomenology, that will necessarily depend on its organization, will be biological or not according to its dependence on the autopoiesis of its components, and will accordingly depend or not on the maintenance of these as autopoietic units. If the new unity is autopoietic, its phenomenology is directly biological and obviously depends on the maintenance of its autopoiesis, which in turn may or may not depend on the autopoiesis of its components.

(iii) The identity of an autopoietic unity is maintained as long as it remains autopoietic; that is, as long as it, as a unity in the physical space, remains a unity in the autopoietic space, regardless of how much it may otherwise be transformed in the process of maintaining its autopoiesis.

(iv) Only after a unity has been constituted as an autopoietic unity (individual) can reproduction take place as a biological phenomenon.

2. PLASTICITY OF ONTOGENY

Ontogeny is the history of the structural transformation of a unity. Accordingly, the ontogeny of a living system is the history of maintenance of its identity through continuous autopoiesis in the physical space. From the mere fact that a physical autopoietic system is a dynamic system, realized through relations of productions of components that imply concrete physical interactions and transformations, it is a necessary consequence of the autopoietic organization of a living system that its ontogeny should take place in the physical space. There are several comments to this notion of ontogeny:

(i) Since the way an autopoietic system maintains its identity depends on its particular way of being autopoietic, that is, on its particular structure, different classes of autopoietic systems have different classes of ontogenies.

(ii) Since an autopoietic system does not have inputs or outputs, all the changes that it may undergo without loss of identity, and, hence, with maintenance of its defining relations, are necessarily determined by its homeostatic organization. Consequently, the phenomenology of an autopoietic system is necessarily always commensurate with the deformations that it suffers without loss of identity, and with the deforming ambience in which it lies. Otherwise it would disintegrate.

(iii) As a consequence of the homeostatic nature of the autopoietic organization, the way the autopoiesis is realized in any given unity may change during its ontogeny, with the sole restriction that this should take place without loss of identity, that is, through uninterrupted autopoiesis.

(iv) Although the changes that an autopoietic system may undergo without loss of identity while compensating its deformations under interactions are determined by its organization, the sequence of such changes is determined by the sequence of these deformations. There are two sources of deformations for an autopoietic system as they appear to be to an observer: one is constituted by the external environment as a source of independent events in the sense that these are not determined by the organization of the system; the other is constituted by the system itself as a source of states which arise from compensations of deformations, but which themselves can constitute deformations that generate further compensatory changes. In the phenomenology of the autopoietic organization these two sources of perturbations are indistinguishable, and in each autopoietic system they braid together to form a single ontogeny. Thus, although in an autopoietic system all changes are internally determined, for an observer its ontogeny partly reflects its history of interactions with an independent ambience. Accordingly, two otherwise equivalent autopoietic systems may have different ontogenies.

(v) An observer beholding an autopoietic system as a unity in a context that he also observes, and which he describes as its environment, may distinguish in it internally and externally generated perturbations, even though these are intrinsically indistinguishable for the autopoietic system itself. The observer can use these distinctions to make statements about the history of the autopoietic system which he observes, and he can use this history to describe an ambience (which he infers) as the domain in which the system exists. He cannot, however, infer from the observed correspondence between the ontogeny of the system and the ambience which this ontogeny describes, or from the environment in which he sees it, a constitutive representation of these in the organization of the autopoietic systems. The continuous correspondence between conduct and ambience revealed during ontogeny is the result of the homeostatic nature of the autopoietic organization, and not of the existence of any representation of the ambience in it; nor is it at all necessary that the autopoietic system should obtain or develop such a representation to persist in a changing ambience. To talk about a representation of the ambience, or the environment, in the organization of a living system may be metaphorically useful, but it is inadequate and misleading to reveal the organization of an autopoietic system.

(vi) The compensatory changes that an autopoietic system may undergo while retaining its identity, may be of two possible kinds according to how its structure is affected by the perturbations: they may be (a) conservative changes in which only the relations between the components change; or they may be (b) innovative changes in which the components themselves change. In the first case, the internal or external interactions causing the deformations do not lead to any change in the way the autopoiesis is realized, and the system remains in the same point in the autopoietic space because its components are invariant; in the second case, on the contrary, the interactions lead to a change in the way the autopoiesis is realized and, hence, to a displacement of the system in the autopoietic space because its components changed. Accordingly, while the first case implies a conservative ontogeny, the second case implies an ontogeny which is also a process of specification of a particular autopoiesis that in its determination is, necessarily, a function of both the plasticity of the components of the system and the history of its interactions.

3. REPRODUCTION, A COMPLICATION OF THE UNITY

Reproduction requires a unity to be reproduced; this is why reproduction is operationally secondary to the establishment of the unity, and it cannot enter as a defining feature of the organization of living systems. Furthermore, since living systems are characterized by their autopoietic organization, reproduction must necessarily have arisen as a complication of autopoiesis during autopoiesis, and its origin must be viewed and understood as secondary to, and independent from the origin of the living organization. The dependence of reproduction upon the existence of the unity to be reproduced is not a trivial problem of precedence, but it is an operational problem in the origin of the reproduced system and its relations with the reproducing mechanism. Accordingly, in order to understand reproduction and its consequences in autopoietic systems we must analyze the operational nature of this process in relation to autopoiesis.

(i) There are three phenomena that must be distinguished in relation to the notion of reproduction; these are replication, copy and self-reproduction. *Replication*. A system which successively generates unities different from itself, but in principle identical to each other, and with an organization which the system determines in the process of their production, is a replicating system. Replication, then, is not different from repetitive production. Any distinction between these processes arises as a matter of description in the emphasis that the observer puts on the origin of the equivalent organization of the successively produced unities, and on the relevance that this equivalence has in a domain different from that in which the repetitive production takes place. Thus, although all molecules are produced by specific molecular and atomic processes that can at least in principle be repeated, only when certain specific kinds of molecules are produced in relation to the cellular activities (proteins and nucleic acids) by certain repeatable molecular concatenations is their production called replication. Such a denomination then, strictly, makes reference only to the context in which the identity of the successively produced molecules is deemed necessary, not to a unique feature of that particular molecular synthesis.

Copy. Copy takes place whenever a given object or phenomenon is mapped by means of some procedure upon a different system, so that an isomorphic object or phenomenon is realized in it. In the notion of copy the emphasis is put on the mapping process, regardless of how this is realized, even if the mapping operation is performed by the model unit itself.

Self-reproduction. Self-reproduction takes place when a unity produces another one with a similar organization to its own, through a process that is coupled to the process of its own production. It is apparent that only autopoietic systems can self-reproduce because only they are realized through a process of self-production (autopoiesis).

(ii) For an observer there is reproduction in all these three processes because he can recognize in each of them a unitary pattern of organization which is embodied in successively generated systems through the three well defined mechanisms. The three processes, however, are intrinsically different because their dynamics give rise to different phenomenologies which appear particularly distinct if one considers the network of systems generated under conditions in which change is allowed in the process of reproduction of the successively embodied pattern of organization. Thus, in replication and copy the mechanism of reproduction is necessarily external to the pattern reproduced, while in self-reproduction it is necessarily identical to it. Furthermore, only in self-copy and self-reproduction can changes in the unities produced which embody the pattern reproduced affect the reproducing mechanism. The consequences of this will be dealt with in the next section, but now it should be clear that the historical interconnections established between independent unities through reproduction varies with the mechanism through which reproduction is achieved.

(iii) In living systems presently known on earth autopoiesis and reproduction are directly coupled and, hence, these systems are truly self-reproducing systems. In fact, in them reproduction is a moment in autopoiesis, and the same mechanism that constitutes one constitutes the other. The consequences of such a coupling are paramount: (a) Self-reproduction must take place during autopoiesis. Accordingly the network of individuals thus produced is necessarily self-contained in the sense that it does not require for its establishment a mechanism independent of the autopoietic determination of the self-reproducing unities. Such would not be the case if reproduction were attained through external copy or replication. (b) Self-reproduction is a form of autopoiesis; therefore, variation and constancy in each reproductive step are not independent and both must occur as expressions of autopoiesis. (c) Variation through self-reproduction of the way the autopoiesis is realized can only arise as a modification during autopoiesis of a pre-existing functioning autopoietic structure; consequently, variation through self-reproduction can only arise from perturbations that require further homeostatic complications to maintain autopoiesis constant. The history of self-reproductively connected autopoietic systems can only be one of continuous complication of autopoiesis.

(iv) The nature of reproduction depends on the nature of the unity. The same goes for its origin. Replication takes place independently of autopoiesis. Copy takes place only in heteropoiesis, and can be deemed to take place in other situations solely as a description. Self-reproduction is exclusively associated to autopoiesis and its origin is bound to it as a historically secondary phenomenon. The reason for this association will be dealt with in the next section.

(v) Notions such as coding, message or information are not applicable to the phenomenon of self-reproduction; their use in the description of this phenomenon constitutes an attempt to represent it in the language of heteropoietic design. In fact, the notions of coding, message and transmission of information apply only to the reduction of uncertainties in the communicative interactions between independent unities under conditions in which the messenger acts as an arbitrary non-participant link. Nucleic acids are constitutive components in the process of autopoiesis, not arbitrary links between independent entities. Thus, in self-reproduction there is no transmission of information between independent entities; the reproducing and the reproduced unities are topologically independent entities produced through a single process of autopoiesis in which all components have a constitutive participation.

4. EVOLUTION, A HISTORICAL NETWORK

A historical phenomenon is a process of change in which each state of the successive states of a changing system arises as a modification of a previous state in a causal transformation, and not *de novo* as an independent occurrence. Accordingly, the notion of history may either be used to refer to the antecedents of a given phenomenon as the succession of events that gave rise to it, or it may be used to characterize the given phenomenon as a process. Therefore, since an explanation is always given in the present as a reformulation of the phenomenon to be explained in the domain of interactions of its components (or of isomorphic elements), the history of a phenomenon as a description of its antecedents cannot contribute to its explanation because the antecedents are not components of the phenomenon which they precede or generate. Conversely, since history as a phenomenon is to be explained in the present as a changing network of sequentially produced events in which each event as a state of the network arises in it as a transformation of the previous state, it follows that although history cannot contribute to explain any phenomenon, it can permit an observer to account for the origin of a phenomenon as a present state in a changing network. This he can do because he has observational (or descriptive) independent access to the different states of the historical process. It is in this context that the phenomenology of autopoietic systems must be considered when viewed in reference to evolution. Biological evolution is a historical phenomenon and as such it must be explained in the present by its reformulation as a historical network constituted through the causal interactions of coupled or independent biological events. Furthermore, biological events depend on the autopoiesis of living systems; accordingly, our aim here is to understand how evolution is defined as a historical process by the autopoiesis of the biological unities.

(i) If by evolution we refer to what has taken place in the history of transformation of terrestrial living systems, evolution is the history of change in the realization of an invariant organization embodied in independent unities sequentially generated through reproductive steps, in which the particular structural realization of each unity arises as a modification of the preceding one (or ones) which, thus, constitutes both its sequential and historical antecedent. Consequently, evolution requires sequential reproduction and change in each reproductive step. Without sequential reproduction as a reproductive process in which the structural realization of each unity in the sequence constitutes the antecedent for the structural realization of the next one, there is no history; without change in each sequential reproductive step, there is no evolution. In fact, sequential transformations in a unity without change of identity constitute its ontogeny, that is, its individual history if it is an autopoietic unity.

(ii) Reproduction by replication or copy of a single unchanging model implies an intrinsic uncoupling between the organization of the unities produced and their producing mechanism. As a consequence, any change in the realization of the organization embodied in the unities successively produced by replication or copy from a single model, can only reflect the ontogenies of the reproducing systems or the independent ontogenies of the units themselves. The result is that under no circumstance in these non-sequential reproductive cases does a change in the structure of a unity affect the structure of the others yet to be produced, and, independently of whether they are autopoietic or not, they do not constitute a historical network, and no evolution takes place. The collection of unities thus produced constitutes a collection of independent ontogenies. In sequential reproduction, as it occurs in self-reproducing systems which attain reproduction through autopoiesis, or as it occurs in those copying systems in which each new unity produced constitutes the model for the next one, the converse is true. In these cases, there are aspects of the structural realization of each unity that determine the structure of the next one by their direct coupling with the reproductive process which is, thus, subordinated to the organization of the reproduced unities. Consequently, changes in these aspects of the structure of the unities sequentially generated, that occur either during their own ontogeny or in the process of their generation, necessarily result in the production of an historical network in which the unities successively produced embody an invariant organization in a changing structure as each unity arises as a modification of the previous one. In general, then, sequential reproduction with the possibility of change in each reproductive step necessarily leads to evolution, and in particular, in autopoietic systems evolution is a consequence of self-reproduction.

(iii) Ontogeny and evolution are completely different phenomena, both in their outlook and in their consequences. In ontogeny, as the history of transformation of a unity, the identity of the unity, in whatever space it may exist, is never interrupted. In evolution, as a process of historical change there is a succession of identities generated through sequential reproduction which constitute a historical network, and that which changes (evolves), the pattern of realization of the successively generated unities exists in a different domain than the unities that embody it. A collection of successive ontogenies in whose structure an observer can see relations of maintained change, but which have not been generated through sequential reproduction, do not constitute an evolving system, not even if they reflect the continuous transformation (ontogeny) of the system that produced them. It is inadequate to talk about evolution in the history of change of a single unity in whatever space it may exist; unities only have ontogenies. Thus, it is inadequate to talk about the evolution of the universe, or the chemical evolution of the earth; one should only talk about the ontogeny of the universe or the chemical history of the earth. Also, there is biological evolution only since there is sequential reproduction of living systems; if there were non self-reproducing autopoietic systems before that, their different patterns of realization did not evolve, and there was only the history of their independent ontogenies.

(iv) Selection, as a process in a population of unities, is a process of

differential realization in a context that specifies the unitary structures that can be realized. In a population of autopoietic unities selection is a process of differential realization of autopoiesis, and, hence, if these are self-reproducing autopoietic unities, of differential self-reproduction. Consequently, if there is sequential reproduction, and the possibility of change in each reproductive step, selection can make the transformation of the reproducible structural patterns realized in each successive unity a recursive function of the domain of interactions which that very same autopoietic unity specifies. If any system that is realized is necessarily adapted in the domain in which it is realized, and adaptation is the condition of possible realization for any system, evolution takes place only if adaptation is conserved by the unities that embody the invariant organization of the evolving lineage. Accordingly, different evolving systems would differ only in the domain in which they are realized, and, hence, in which selection takes place, not in whether they are adaptive or not. Thus, evolution in self-reproducing living systems that maintain their identity in the physical space (while the realization of their autopoietic organization is commensurate with the restrictions of the ambience in which they exist), is necessarily a process of continued adaptation because only those of them whose autopoiesis can be realized reproduce, regardless of how much the way they are autopoietic may otherwise change in each reproductive step.

(v) For evolution to take place as a history of change in the realization of an invariant organization embodied in successively generated unities, reproduction must allow for structural change in the sequentially reproduced unities. In present living systems reproduction takes place as a modification of autopoiesis and is bound to it. This was to be expected. Originally many kinds of autopoietic unities were probably formed which would mutually compete for the precursors. If any class of them had any possibility of self-reproduction, it is evident that it would immediately displace through selection the other non-reproducing forms. The onset of the history of self-reproduction need not have been complex; for example, in a system with distributed autopoiesis mechanical fragmentation is a form of self-reproduction. Evolution through selection would appear with the enhancement of those features of the autopoietic unities that facilitated their fragmentation (and hence the regularity and frequency of self-reproduction) to the extent of making it independent of external accidental forces. Once the most simple self-reproducing process takes place in an autopoietic system, evolution is on its course and self-reproduction can enter in a history of change, with the ensuing total displacement of any co-existing non-self-reproducing autopoietic unities. *Hence the linkage between autopoiesis and self-reproduction in terrestrial living systems.* Of course it is not possible to say now what actually took place in the origin of biological evolution, but this does not seem to offer an insurmountable conceptual difficulty. The fact is that in present day living systems self-reproduction is crucially associated to nucleic acids and their role in protein specification. We think that this could not have been so if the nucleic acid-protein association were not a condition virtually constitutive of the original autopoietic process which was secondarily associated to reproduction and variation; and we think that this is so because only uncompensated changes at the level of the autopoietic process itself can be incorporated (through sequential reproduction) as reproducible changes of the autopoietic organizations of the next unity in a manner that allows for evolution to take place. What is not apparent, though, is whether or not there have been other modes of autopoietic realization, and other sources of variation, than those associated with the nucleic acid-protein system, in the history of terrestrial living systems. Whichever the case, once self-reproduction appears in autopoiesis, any perturbation which modifies the way in which the autopoiesis is realized, can, in principle, be reproduced in the next generation, and, thus, be the source of variations if the change affected those processes involved in reproduction. Accordingly the phenomenology of biological evolution and its origin rests on the inception of two processes: self-reproduction and variation. One refers to possible forms of complication of the autopoiesis, the other to the introduction of perturbations which irreversibly modify the way the autopoiesis is realized. Both undergo historical transformations, which, though coupled, are not equivalent.

(vi) Of the two possible mechanisms that can give rise to sequential reproduction, the only one which is accessible to autopoietic systems in the absence of an independent copying mechanism is self-reproduction, because of the coincidence between the reproducing mechanisms and the reproducing unity. Sequential reproduction through copy takes place at present only in relation to the operation of living systems in their domain of interactions, particularly in cultural learning; cultural evolution takes place through sequential copy of a changing model in the process of social indoctrination generation after generation.

(vii) A species is a population or collection of populations of reproductively interconnected individuals which are thus nodes in a historical network. Genetically these individuals share a genetic pool, that is, a fundamentally

equivalent pattern of autopoietic realization under historical transformations. Historically, a species arises when a reproductive network of this kind develops an independent reproductive network as a branch which by being an independent historical network (reproductively separated) has an independent history. It is said that what evolves is the species and that the individuals in their historical existence are subordinated to this evolution. In a superficial descriptive sense this is meaningful because a particular species as an existing collection of individuals represents continuously the state of a particular historical network in its process of becoming one, and, if described as a state of a historical network, a species necessarily appears in a process of transformation. Yet, the species exists as a unity only in the historical domain, while the individuals that constitute the nodes of the historical network exist in the physical space. Strictly, a historical network is defined by each and every one of the individuals which constitute its nodes, but it is at any moment represented historically by the species as the collection of all the simultaneously existing nodes of the network; in fact, then, a species does not evolve because as a unity in the historical domain it only has a history of change. What evolves is a pattern of autopoietic realization embodied in many particular variations in a collection of transitory individuals that together define a reproductive historical network. Thus, the individuals, though transitory, are essential, not dispensable, because they constitute a necessary condition for the existence of the historical network which they define. The species is only an abstract entity in the present, and although it represents a historical phenomenon it does not constitute a generative factor in the phenomenology of evolution, it is its result.

5. SECOND AND THIRD ORDER AUTOPOIETIC SYSTEMS

Whenever the conduct of two or more unities is such that there is a domain in which the conduct of each one is a function of the conduct of the others, it is said that they are coupled in that domain. Coupling arises as a result of the mutual modifications that interacting unities undergo in the course of their interactions without loss of identity. If the identity of the interacting unities is lost in the course of their interactions, a new unity may be generated as a result of it, but no coupling takes place. In general, however, coupling leads also to the generation of a new unity that may exist in a different domain from the domain in which the component-coupled unities retain their identity. The way in which this takes place, as well as the domain in which the new unity is realized, depend on the properties of the component unities. Coupling in living systems is a frequent occurrence; the following comments are meant to show that the nature of the coupling of living systems is determined by their autopoietic organization.

(i) Autopoietic systems can interact with each other without loss of identity as long as their respective paths of autopoiesis constitute reciprocal sources of compensable disturbances. Furthermore, due to their homeostatic organization autopoietic systems can couple and constitute a new unity while their individual paths of autopoiesis become reciprocal sources of specification of each other's ambience, if their reciprocal deformations do not overstep their corresponding ranges of tolerance for variation without loss of autopoiesis. As a consequence the coupling remains invariant while the coupled systems undergo structural changes selected through the coupling and, hence, commensurate with it. These considerations also apply to the coupling of autopoietic and non-autopoietic unities with obvious modifications in relation to the retention of identity of the latter. In general, then, the coupling of autopoietic systems with other unities, autopoietic or not, is realized through their autopoiesis. That coupling may facilitate autopoiesis requires no further discussion, and that this facilitation may take place through the particular way in which the autopoiesis of the coupled unities is realized has already been said. It follows that selection for coupling is possible, and that through evolution under a selective pressure for coupling a composite system can be developed (evolved) in which the individual autopoiesis of every one of its autopoietic components is subordinated to an ambience defined through the autopoiesis of all the other autopoietic components of the composite unity. Such a composite system will necessarily be defined as a unity by the coupling relations of its component autopoietic systems in a space that the nature of the coupling specifies, and will remain as a unity as long as the component systems retain their autopoiesis which allows them to enter into those coupling relations.

A system generated through the coupling of autopoietic unities may, on a first approximation, be seen by an observer as autopoietic to the extent that its realization depends on the autopoiesis of the unities which integrate it. Yet, if such a system is not defined by relations of production of components that generate these relations and define it as a unity in a given space, but by other relations, either between components or processes, it is not an autopoietic system and the observer is mistaken. The apparent autopoiesis of such a system is incidental to the autopoiesis of the coupled unities which constitute it, and not intrinsic to its organization; the mistake of the observer,

therefore, lies in that he sees the system of coupled autopoietic unities as a unity in his perceptive domain in terms other than those defined by its organization. In contrast, a system realized through the coupling of autopoietic unities and defined by relations of production of components that generate these relations and constitute it as a unity in some space, is an autopoietic system in that space regardless of whether the components produced coincide or not with the unities which generate it through their coupled autopoiesis. If the autopoietic system thus generated is a unity in the physical space it is a living system. An autopoietic system whose autopoiesis entails the autopoiesis of the coupled autopoietic unities which realize it, is an autopoietic system of higher order.

In general, the actual recognition of an autopoietic system poses a cognitive problem that has both to do with the capacity of the observer to recognize the relations that define the system as a unity, and with his capacity to distinguish the boundaries which delimit this unity in the space in which it is realized. Since it is a defining feature of an autopoietic system that it should specify its own boundaries, a proper recognition of an autopoietic system as a unity requires that the observer performs an operation of distinction that defines the limits of the system in the same domain in which it specifies them through its autopoiesis. If this is not the case he does not observe the autopoietic system as a unity, even though he may conceive it. Thus, presently, the recognition of a cell as a molecular autopoietic unity offers no serious difficulty because we can identify the autopoietic nature of its organization, and interact visually, mechanically and chemically, with one of the boundaries (membrane) which its autopoiesis generates as an interface which delimits it as a three dimensional physical unity. In addition the observer may have two kinds of difficulties in the identification of an autopoietic unity as an actually distinguishable system: on the one hand, he may treat the system as a unity by making an operation of distinction in a space different from the space in which it is realized because he has not yet properly recognized the relations of production of components that constitute it, and, hence, cannot recognize the topological relations which specify its unity in that space; on the other hand, due to his own mode of autopoietic organization (and, hence, cognitive structure) he may be unable to interact in the space in which the system is realized as a unity, and, hence, he may be unable to observe it as a unity because he cannot specify the proper perceptual dimensions. In the first case, the observer makes a unity distinction which is not commensurate with the autopoietic system, and he thus defines and operates with a different unity; in the second case he makes no distinction at all, and he has no unity with which to operate. In either case the phenomenology of the autopoietic unity remains unobservable. However, if there is no misidentification of the system, even if its unity is not yet operationally observable, its phenomenology can be asserted by the recognition of the organization that constitutes it.

(ii) An autopoietic system can become a component of another system if some aspects of its path of autopoietic change can participate in the realization of this other system. As has been said, this can take place in the present through a coupling that makes use of the homeostatic resorts of the interacting systems, or through evolution by the recursive effect of a maintained selective pressure on the course of transformation of a reproductive historical network, which results in a subordination of the individual component autopoiesis (through historical change in the way these are realized) to the ambience of reciprocal perturbations which they specify. Whichever the case, an observer can describe an autopoietic component of a composite system as playing an allopoietic role in the realization of the larger system which it contributes to realize through its autopoiesis. In other words, the autopoietic unity functions in the context of the composite system in a manner that the observer would describe as allopoietic. Yet, the allopoietic function is exclusively a feature of the description and pertains to a frame of reference defined by the observer. As we described in Chapter I, there are allopoietic machines whose organization is intrinsically different from autopoietic machines, and can be described (with no reference to function) by pointing out that the product of their operation is different from themselves. Accordingly, when an autopoietic system is described as having an allopoietic role as a component in a larger system, the description makes reference only to its participation in the production of relations that adopt the form proper to an allopoietic system, but nothing is implied about function which is proper only in the domain of heteropoietic human design.

(iii) If the autopoiesis of the component unities of a composite autopoietic system conforms to allopoietic roles that through the production of relations of constitution, specification and order define an autopoietic space, the new system becomes in its own right an autopoietic unity of second order. This has actually happened on earth with the evolution of the multicellular pattern of organization. When this occurs, the component (living) autopoietic systems become necessarily subordinated, in the way they realize their autopoiesis, to the maintenance of the autopoiesis of the higher order autopoietic unity which, through their coupling, they define topologically in the physical

space. If the higher order autopoietic system undergoes self-reproduction (through the self-reproduction of one of its component autopoietic unities or otherwise), an evolutionary process begins in which the evolution of the manner of realization of the component autopoietic systems is necessarily subordinated to the evolution of the manner of realization of the composite unity. Furthermore, it is to be expected that if the proper contingencies are given, higher order autopoietic unities will be formed through selection. In fact, if coupling arises as a form of satisfying autopoiesis, a second order unity formed from previous autopoietic systems will be more stable, the more stable the coupling is. However, the most stable condition for coupling appears if the unity organization is precisely geared to maintain this organization, this is, if the unity becomes autopoietic. There is then an ever present selective pressure for the constitution of higher order autopoietic systems from the coupling of lower order autopoietic unities which on earth is apparent in the occurrence of multicellular systems, if not in that of the eucariotic cell itself. It seems that the only limit to the process of constitution of autopoietic unities of higher order is that imposed by the circumstances under which a unity can be specified in a given space.

PRESENCE OF AUTOPOIESIS

Autopoiesis in the physical space is necessary and sufficient to characterize a system as a living system. Reproduction and evolution as they occur in the known living systems, and all the phenomena derived from them, arise as secondary processes subordinated to their existence and operation as autopoietic unities. Hence, the biological phenomenology is the phenomenology of autopoietic systems in the physical space, and a phenomenon is a biological phenomenon only to the extent that it depends in one way or another on the autopoiesis of one or more physical autopoietic unities.

1. BIOLOGICAL IMPLICATIONS

A living system is a living system because it is an autopoietic system in the physical space, and it is a unity in the physical space because it is defined as a unity in that space by and through its autopoiesis. Accordingly, any structural transformation that a living system may undergo maintaining its identity must take place in a manner determined by and subordinated to its defining autopoiesis; hence, in a living system loss of autopoiesis is disintegration as a unity and loss of identity, that is, death.

(i) The physical space is defined by components that can be determined by operations that characterize them in terms of properties such as masses, forces, accelerations, distances, fields, etc. Furthermore, such properties themselves are defined by the interactions of the components that they characterize. In the physical space two kinds of phenomenologies can take place according to the way the components participate in their generation, namely, statical and mechanical (machine like). The statical phenomenology is a phenomenology of relations between properties of components; the mechanical phenomenology is a phenomenology of relations between processes realized through the properties of components. What about the biological phenomenology, that is, what about the phenomenology of autopoietic systems, which, as such, takes place in the physical space? Since a living system is defined as a system by the concatenation of processes of production of components that generate the processes that produce them and constitute

the system as a unity in the physical space, biological phenomena are necessarily phenomena of relations between processes which satisfy the autopoiesis of the participant living systems. Accordingly, under no circumstances is a biological phenomenon defined by the properties of its component elements, but it is always defined and constituted by a concatenation of processes in relations subordinated to the autopoiesis of at least one living system. Thus, the accidental collision of two running animals, as a bodily encounter of living systems, is not a biological phenomenon (even though it may have biological consequences), but the bodily contact of two animals in courtship is. Strictly, then, although biological and statical phenomena are physical phenomena because they are realized through the properties of their physical components, they differ because statical phenomena are phenomena of relations between properties of components (as previously defined), while biological phenomena are phenomena of relations between processes. Therefore, biological phenomena as phenomena of relations between processes are a subclass of the mechanical phenomena which constitute them, and are defined through the participation of these processes in the realization of at least one autopoietic system. The phenomenology of living systems, then, is the mechanical phenomenology of physical autopoietic machines.

(ii) As the mechanical phenomenology of physical autopoietic machines, the biological phenomenology is perfectly defined, and, hence, amenable to theoretical treatment through the theory of autopoiesis. It follows that such a theory as a formal theory will be a theory of the concatenation of processes of production that constitute autopoietic systems, and not a theory of properties of components of living systems. It also follows that a theoretical biology would be possible as a theory of the biological phenomenology, and not as the application of physical or chemical notions, which pertain to a different phenomenological domain, to the analysis of the biological phenomena. In fact, it should be apparent now that any attempt to explain a biological phenomenon in statical or non-autopoietic mechanical terms would be an attempt to reformulate it in terms of relations between properties of components, or relations between processes which do not involve an autopoietic unity in the physical space, and would fail to reformulate it. Since a biological phenomenon takes place through the operation of components, it is always possible to abstract from it component processes that can be adequately described in statical or non-autopoietic mechanical terms, because, as abstracted processes, they in fact correspond to statical or allopoietic mechanical phenomena. In such a case, any connection between the statical or non-autopoietic mechanical processes and the biological phenomenon from which the observer abstracts them, is provided by the observer who considers both simultaneously; the biological phenomenon, however, is not and cannot be captured by these explanations which, necessarily, remain a reformulation of a phenomenon in a non-autopoietical phenomenological domain. A biological explanation must be a reformulation in terms of processes subordinated to autopoiesis, that is, a reformulation in the biological phenomenological domain.

(iii) An adequate theory of the biological phenomena should permit the analysis of the dynamics of the concrete components of a system in order to determine whether or not they participate in processes that integrate a biological phenomenon. In fact, no matter how much we think we understand biological problems today, it is apparent that without an adequate theory of autopoiesis it will not be possible to answer questions such as: 'Given a dynamic system, what relations should I observe between its concrete components to determine whether or not they participate in processes that make it a living system?'; or, 'Given a set of components with well-defined properties, in what processes of production can they participate so that the components can be concatenated to form an autopoietic system?' The answers to these questions are essential if one wants to solve the problem of the origin of living systems on earth. The same questions must be answered if one wants to design a living system. In particular, it should be possible to determine from biological theoretical considerations which relations should be satisfied by any set of components if these are to participate in processes that constitute an autopoietic unity. Whether one may or may not want to make an autopoietic system is, of course, a problem that pertains to the ethical domain. However, if our characterization of living systems is adequate it is apparent that they could be made at will. What remains to be seen is whether such a system has already been made by man, although unwittingly, and with what consequences.

(iv) The characterization of living systems as physical autopoietic systems must be understood as having universal value, that is, autopoiesis in the physical space must be viewed as defining living systems anywhere in the universe, however different they may otherwise be from terrestrial ones. This is not to be considered as a limitation of our imagination, nor as a denial that there might exist still unimagined complex systems. It is a statement about the nature of the biological phenomenology: the biological phenomenology is not less and not more than the phenomenology of autopoietic systems in the physical space.

2. EPISTEMOLOGICAL IMPLICATIONS

(i) The basic epistemological question in the domain of the biological problems is that which refers to the validity of the statements made about biological systems. It is presently obvious that scientific statements made about the universe acquire their validity through their operative effectiveness in their application in the domain where they pretend validity. Yet any observation, even that one which permits us to recognize the operational validity of a scientific statement, implies an epistemology, a body of conceptual explicit or implicit notions that determines the perspective of the observations and, hence, what can and what cannot be observed, what can and what cannot be validated by its operative effectiveness, what can and what cannot be explained by a given body of theoretical concepts. This has been a fundamental problem in the conceptual and experimental handling of the biological phenomena, as it is apparent in the history of biology, which reveals a continuous search for the definition of the biological phenomenology in a manner such that would permit its complete explanation through well-defined notions, and, accordingly, its complete validation in the observational domain. In this respect, evolutionary and genetic notions have been the most successful. Yet these notions alone are insufficient because, although they provide a mechanism for historical change, they do not adequately define the domain of the biological phenomenology. In fact, evolutionary and genetic notions (by emphasizing generational change) treat the species as the source of all biological order, showing that the species evolves while the individuals are transient components whose organization is subordinated to its historical phenomenology. However, since the species is, concretely at any moment, a collection of individuals capable in principle of interbreeding, it turns out that what would define the organization of individuals is either an abstraction, or something that requires the existence of well-defined individuals to begin with. Where does the organization of the individual come from? Which is the mechanism for its determination? This difficulty cannot be solved on purely evolutionary and genetic arguments, since it is apparent (even for evolutionists and geneticists) that any attempt to overcome it by resorting to other notions of comprehensive nature, is doomed to failure if it does not provide us with a mechanism to account for the phenomenology of the individual. Such is the case when some sort of preformism is introduced by applying informational notions at the molecular level (nucleic acids or proteins); or when organismic notions are used that emphasize the unitary character of living systems but do not provide a mechanism for the definition of the individual. These notions fail because they imply the validity of the same notion that they want to explain.

As is apparent from all that has been said, the key to the understanding of the biological phenomenology is the understanding of the organization of the individual. We have shown this organization to be the autopoietic organization. Furthermore, we have shown that this organization and its origin are fully explainable with purely mechanistic notions which are valid for any mechanistic phenomenon in any space, and that once the autopoietic organization is established it determines an independent phenomenological subdomain of the mechanistic phenomenology, the domain of the biological phenomena. As a result, the biological domain is fully defined and self-contained, no additional notions are necessary, and any adequate biological explanation has the same epistemological validity that any mechanistic explanation of any mechanistic phenomenon in the physical space has.

(ii) A phenomenological domain is defined by the properties of the unity or unities that constitute it, either singly or collectively through their transformations or interactions. Thus, whenever a unity is defined, or a class or classes of unities are established which can undergo transformations or interactions, a phenomenological domain is defined. Two phenomenological domains intersect only to the extent that they have common generative unities, that is, only to the extent that the unities that specify them interact; otherwise they are completely independent and, obviously, they cannot generate each other without transgressing the domains of relations of their respective specifications. Conversely, one phenomenological domain can generate unities that define a different phenomenological domain, but such a domain is specified by the properties of the new different unities, not by the phenomenology that generates them. If this were not the case the new unities would not be in fact different unities, but they would be unities of the same class of units that generate the parental phenomenological domain, and they would generate a phenomenological domain identical to it. Autopoietic systems do generate different phenomenological domains by generating unities whose properties are different from the properties of the unities that generate them. These new phenomenological domains are subordinated to the phenomenology of the autopoietic unities because they depend on these for their actual realization, but they are not determined by them; they are only determined by the properties of their originating unities regardless of how these were originated. One phenomenological domain cannot be explained by relations which are valid for another domain; this is a general case which

applies also to the different phenomenological domains generated through the operation of autopoietic systems. Accordingly, as an autopoietic system cannot be explained through statical or non-autopoietic mechanical relations in the space in which it exists, but it must be explained through autopoietic mechanical relations in the mechanical domain, the phenomena generated through interactions of autopoietic unities must be explained in the domain of interactions of the autopoietic unities through the relations that define that domain.

(iii) The development of the Darwinian notion of evolution with its emphasis on the species, natural selection and fitness, had an impact in human affairs that went beyond the explanation of diversity and its origin in living systems. It had sociological significance because it seemed to offer an explanation of the social phenomenology in a competitive society, as well as a scientific justification for the subordination of the destiny of the individuals to the transcendental values supposedly embodied in notions such as mankind, the state, or society. In fact, the social history of man shows a continuous search for values that explain or justify human existence, as well as a continuous use of transcendental notions to justify social discrimination, slavery, economical subordination and political submission of the individuals, isolated or collectively, to the design or whim of those who pretend to represent the values contained in those notions. For a society based on economic discrimination, competitive ideas of power and subordination of the citizen to the state, the notions of evolution, natural selection and fitness (with their emphasis on the species as the perduring historical entity maintained through the dispensability of transient individuals) seemed to provide a biological (scientific) justification for its economic and social structure. It is true on biological grounds that what evolves is mankind as the species *Homo sapiens*. It is true on biological grounds that competition participates in the specification of evolutionary change even in man. It is true that under the laws of natural selection the individuals most apt in the features which are favorably selected survive, or have reproductive advantages over the others, and that those which do not survive or are less successful in the reproductive sense do not contribute or contribute less to the historical destiny of the species. Thus, from the Darwinian perspective it seemed that the role of the individual was to contribute to the perpetuation of the species, and that all that one had to do for the well-being of mankind was to let the natural phenomena follow their course. Science, biology, appeared to justify the notion 'anything for the benefit of mankind', whatever the intention or purpose of whoever uttered it first. We have shown, however, that these arguments are not valid to justify the subordination of the individual to the species, because the biological phenomenology is determined by the phenomenology of the individuals, and without individuals there is no biological phenomenology whatsoever. The organization of the individual is autopoietic and upon this fact rests all its significance: it becomes defined through its existing, and its existing is autopoietic. Thus, biology cannot be used anymore to justify the dispensability of the individuals for the benefit of the species, society or mankind under the pretense that its role is to perpetuate them. Biologically the individuals are not dispensable.

(iv) Biological phenomena depend upon the autopoiesis of the individuals involved; thus, there are biological systems that arise from the coupling of autopoietic unities, some of which may even constitute autopoietic systems of higher order. What about human societies, are they, as systems of coupled human beings, also biological systems? Or, in other words, to what extent do the relations which characterize a human society as a system constitutively depend on the autopoiesis of the individuals which integrate it? If human societies are biological systems the dynamics of a human society would be determined through the autopoiesis of its components. If human societies are not biological systems, the social dynamics would depend on laws and relations which are independent of the autopoiesis of the individuals which integrate them. The answer to this question is not trivial and requires considerations which in addition to their biological significance have ethical and political implications. This is obviously the case, because such an answer requires the characterization of the relations which define a society as a unity (a system), and whatever we may say biologically will apply in the domain of human interactions directly, either by use or abuse, as we saw it happen with evolutionary notions. In fact no position or view that has any relevance in the domain of human relations can be deemed free from ethical and political implications nor can a scientist consider himself alien to these implications. This responsibility we are ready to take, yet since we – Maturana and Varela – do not fully agree on an answer to the question posed by the biological character of human societies from the vantage point of this characterization of the biological organization, we have decided to postpone this discussion.

3. COGNITIVE IMPLICATIONS

The domain of interactions of an autopoietic unity is the domain of all the

deformations that it may undergo without loss of autopoiesis. Such a domain is determined for each unity by the particular mode through which its autopoiesis is realized in the space of its components, that is, by its structure. It follows that the domain of interactions of an autopoietic unity is necessarily bounded, and that autopoietic unities with different structures have different domains of interactions. Furthermore, an observer can consider the way in which an autopoietic system compensates its deformations as a description of the deforming agent that he sees acting upon it, and the deformation suffered by the system as a representation of the deforming agent. However, since the domain of interactions of an autopoietic system is bounded, an observer of an autopoietic system can describe entities external to it (by interacting with them) which it cannot describe because it cannot interact with them or it cannot compensate the deformations which these cause in it. The domain of all the interactions in which an autopoietic system can enter without loss of identity is its cognitive domain; or, in other words, the cognitive domain of an autopoietic system is the domain of all the descriptions which it can possibly make. Accordingly, for any autopoietic system its particular mode of autopoiesis determines its cognitive domain and hence its behavioral diversity, and it follows that the cognitive domain of an autopoietic system changes along its ontogeny only to the extent that its mode of autopoiesis changes.

We shall not explore in this book all the implications that the proper characterization of the biological phenomenology has within the domain of cognition, but we shall make four remarks in order to show the dependence of this domain upon the autopoietic organization of the individual.

(i) For any autopoietic system its cognitive domain is necessarily relative to the particular way in which its autopoiesis is realized. Also, if knowledge is descriptive conduct, it is relative to the cognitive domain of the knower. Therefore, if the way in which the autopoiesis of an organism is realized changes during its ontogeny, the actual knowledge of the organism (its conduct repertoire) also changes; knowledge, then, is necessarily always a reflection of ontogeny of the knower because ontogeny as a process of continuous structural change without loss of autopoiesis is a process of continuous specification of the behavioral capacity of the organism, and hence, of its actual domain of interactions. Intrinsically, then, no absolute knowledge is possible, and the validation of all possible relative knowledge is attained through successful autopoiesis.

(ii) Autopoietic systems may interact with each other under conditions that result in behavioral coupling. In this coupling, the autopoietic conduct of an organism A becomes a source of deformation for an organism B, and the compensatory behavior of organism B acts, in turn, as a source of deformation of organism A, whose compensatory behavior acts again as a source of deformation of B, and so on recursively until the coupling is interrupted. In this manner, a chain of interlocked interactions develops such that, although in each interaction the conduct of each organism is constitutively independent in its generation of the conduct of the other, because it is internally determined by the structure of the behaving organism only, it is for the other organism, while the chain lasts, a source of compensable deformations which can be described as meaningful in the context of the coupled behavior. These are communicative interactions. In other words, if the interacting organisms as dynamic systems have continuously changing structures, and if they reciprocally select in each other their respective paths of ontogenic structural changes through their interactions without loss of autopoiesis, then they generate, as a recursive or expanding domain of communicative interactions, interlocked ontogenies that together constitute a domain of mutually triggering consensual conducts that becomes specified during its generation. Such a consensual domain of communicative interactions in which the behaviorally coupled organisms orient each other with modes of behavior whose internal determination has become specified during their coupled ontogenies, is a linguistic domain. In such a consensual domain of interactions the conduct of each organism may be treated by an observer as constituting a connotative description of the conduct of the other, or, in his domain of description as an observer, as a consensual denotation of it. Communicative and linguistic interactions are intrinsically not informative; organism A does not and cannot determine the conduct of organism B because due to the nature of the autopoietic organization itself every change that an organism undergoes is necessarily and unavoidably determined by its own organization. A linguistic domain, then, as a consensual domain that arises from the coupling of the ontogenies of otherwise independent autopoietic systems, is intrinsically non-informative, even though an observer, by neglecting the internal determination of the autopoietic systems which generate it, may describe it as if it were so. Phenomenologically the linguistic domain and the domain of autopoiesis are different domains, and although one generates the elements of the other, they do not intersect.

(iii) An autopoietic system capable of interacting with its own states (as an organism with a nervous system can do), and capable of developing with

others a linguistic consensual domain, can treat its own linguistic states as a source of deformations and thus interact linguistically in a closed linguistic domain. Such a system has two remarkable properties:

1. Through recursive interactions with its linguistically generated states it can treat some of these states as objects of further interactions, giving rise to a metadomain of consensual distinctions that appears to an observer as a domain of interactions with representations of interactions. When this happens the system operates as an observer. The domain of such recursive interactions is, in principle, infinite because once the system has attained the mechanism for doing so there is no moment in which it will not be in the position of recursively interacting with its own states, unless autopoiesis is lost. Whether an autopoietic system with this capacity does in fact generate an endless series of different states during its ontogeny depends, obviously, on whether its history of linguistic interactions in the metadomain of descriptions has significance for the circumstantial realization of the autopoiesis of the interacting organisms.

2. A living system capable of being an observer can interact with those of its own descriptive states which are linguistic descriptions of itself. By doing so it generates the domain of self-linguistic descriptions within which it is an observer of itself as an observer, a process which can be necessarily repeated in an endless manner. We call this domain the domain of self-observation and we consider that self-conscious behavior is self-observing behavior, that is, behavior within the domain of self-observation. The observer as an observer necessarily always remains in a descriptive domain, that is, in a relative cognitive domain. No description of an absolute reality is possible. Such a description would require an interaction with the absolute to be described, but the representation which would arise from such an interaction would necessarily be determined by the autopoietic organization of the observer, not by the deforming agent; hence, the cognitive reality that it would generate would unavoidably be relative to the knower.

In every explanation, be this an actual concrete reproduction, a formal representation or a purely rational description, the reformulation of the phenomenon to be explained resorts to the same notions (identity, exclusion, succession, etc.). There is, then, a universal logic, valid for all phenomenological domains, that refers to the relations possible between the unities that generate these domains, and not to the particular properties of the generating unities. We have applied this logic (it could not have been otherwise) in this book, and the validity of our arguments, as the validity of any rational argument or concrete phenomenological realization, rests on its validity. Furthermore, we have in principle shown through its application that the phenomenology of autopoietic systems generates observers, and through them the phenomenology of description within which this logic is also valid. For epistemological reasons, in order to say all that we have said about living systems, we had to assume a space (the physical space) within which the phenomenology of autopoiesis of living systems takes place. To the extent that we have been successful (free from logical and experiential contradictions), we can conclude that such a space is ontologically a space within which the logic that we have applied in our description is intrinsically valid. If this were not the case we could not have done what we have done in terms of characterizing living systems, or of showing how these may generate systems capable of their own description. We cannot characterize this space in absolute terms. In linguistic interactions, all that we can do is to describe through linguistic behavior and construct further descriptions based on these descriptions which always remain in the same domain of operations defined in relation to the operating system.

A prediction is a statement of a case within a relational matrix; it is a cognitive statement, and as such it takes place within a descriptive domain. Thus, unless mistakes are made, if all the relations that define the particular matrix within which the prediction is made are properly taken, the prediction is valid. Errors of interpretations may arise only by mis-application, that is, by pretending that the observer makes a prediction in one matrix when he is making it in another. In particular, predictions in the physical space are possible, because a description, as an actual behavior, exists in a matrix of interactions which (by constitution) has a logical matrix necessarily isomorphic with the substratum matrix within which it takes place, not because we have an absolute knowledge of the universe. These cognitive relations are valid for the possible cognitive phenomenology generated by any closed system. Living systems are an existential proof; they exist only to the extent that they can exist. The fantasy of our imagination cannot deny this. Living systems are concatenations of processes in a mechanistic domain; fantasies are concatenations of descriptions in a linguistic domain. In the first case, the concatenated unities are processes; in the second case, they are modes of linguistic behavior.

Autopoiesis solves the problem of the biological phenomenology in general by defining it. New problems arise, and old ones appear in a different perspective; in particular, those which refer to the origin of living systems on earth

(eobiogenesis and neobiogenesis), and those which refer to the particular organization through which recursive descriptive interactions take place in animals (the nervous system). Autopoietic systems define the world in which they can exist in relation to their autopoiesis, and some interact recursively with this world through their descriptions, it being impossible for them to step out of this relative descriptive domain through descriptions. This demands an entirely new cognitive outlook: there is a space in which different phenomenologies can take place; one of these is autopoiesis; autopoiesis generates a phenomenological domain, this is cognition.

APPENDIX

THE NERVOUS SYSTEM

The phenomenology of an organism as a unity is the phenomenology of its autopoiesis. The changes that an organism undergoes while maintaining its autopoiesis constitute its conduct. The conduct of an organism is revealed to an observer by the changes that it causes in the ambience (including the observer) in which it exists. Accordingly, the conduct which an observer beholds in any organism, however complex it may seem, is always an expression of the autopoiesis of the observed organism, and as such, it always arises through a phenomenology that takes places in the present because history is not a causal component in the mechanism of autopoiesis (see Chapter IV). Yet it appears to us as subjects of self-observation and as observers of the conduct of other organisms that past experiences determine our and their conduct in the present as if, embodied in modifications of the nervous system, they were causal components in the mechanism which generates behavior. It appears, therefore, as if the operation of the organism as a state-determined system in which time is not a component were determined by temporal phenomena, and we speak of learning, memory and recall as embodiments of the past. We consider that this contradiction arises from not distinguishing what pertains to the phenomenology of the autopoiesis from what pertains to the domain of interactions of the organism as a unity, and, thus, from an inadequate evaluation of the coupling of the structure of the nervous system to the ontogeny of the organism. Accordingly, our purpose in this Appendix about the nervous system is to consider its organization as a neuronal network and to evaluate this coupling in which past and present arise as new dimensions from the recursive interactions of the organism with its own states.

A. THE NERVOUS SYSTEM AS A SYSTEM

The nervous system is a network of interacting neurons coupled in three ways to the organism of which it is a component:

(i) The organism, including the nervous system, provides the physical and

biochemical environment for the autopoiesis of the neurons as well as for all other cells, and, hence, is a possible source of physical and biochemical perturbations which may alter the properties of the neurons and thus lead to (ii) or (iii).

(ii) There are states of the organism (physical and biochemical) which change the state of activity of the nervous system as a whole by acting upon the receptor surfaces of some of its component neurons, and thus lead to (iii).

(iii) There are states of the nervous system which change the state of the organism (physical or biochemical) and lead recursively to (i) and (ii).

Through this coupling the nervous system participates in the generation of the autopoietic relations which define the organism which it integrates, and, accordingly, its structure is subordinated to this participation.

1. *The Neuron*

Neurons determine their own boundaries through their autopoiesis; therefore they are the anatomical units of the nervous system. There are many classes of neurons that can be distinguished by their shapes, but all of them, regardless of the morphological class to which they belong, have branches which put them in direct or indirect operational relations with other otherwise separated neurons. Functionally, that is, viewed as an allopoietic component of the nervous system, a neuron has a collector surface, a conducting element, and an effector surface, whose relative positions, shapes and extensions are different in different classes of neurons. The collector surface is that part of the surface of a neuron where it receives afferent influences (synaptic or not) from the effector surfaces of other neurons or its own. The effector surface of a neuron is that part of its surface which either directly (by means of synaptic contacts) or indirectly (through its synaptic or nonsynaptic action on other kinds of cells) affects the collector surface of other neurons or its own. Depending on its kind, a neuron may have its collector and effector surfaces completely or partly separated by a conducting element (absence or presence of presynaptic inhibition), or it may have both collector and effector surfaces completely interspaced, with no conducting element between them (amacrine cells). The interactions between collector and effector surfaces may be excitatory or inhibitory according to the kinds of neurons involved. Excitatory afferent influences cause a change in the state of activity of the collector surface of the receiving neuron which may lead to a change in the state of activity of its effector surface, while the inhibitory influences impinging on it shunt off the effect of the afferent influences on its receptor surface so that this effect does not at all reach its effector surface, or reaches this surface with reduced effectiveness.

Operationally the state of activity of a neuron, characterized by the state of activity of its effector surface, is determined by both its internal structure (membrane properties, relative thickness of branches, and in general all structural relations which determine its possible states) and the afferent influences impinging on its receptor surface. Conversely, the effectiveness of a neuron in changing the state of activity of other neurons depends both on the internal structure of these, and on the relative effectiveness of its action on their receptor surfaces with respect to the other afferent influences that these neurons receive. This is so because excitatory and inhibitory influences do not add linearly in the determination of the state of activity of a neuron, but rather have effects which depend on the relative position of their points of action with respect to each other and with respect to the effector surface of the receiving cell. Furthermore, the internal structure of a neuron changes along its life history, both as a result of its autonomous genetic determinations and as a result of the circumstances of its operations during the ontogeny of the organism. Thus, neurons are not static entities whose properties remain invariant. On the contrary, they change. This has three general consequences:

(i) There are many configurations of afferent (input) influences on the receptor surface of a neuron which produce the same configuration of efferent (output) activity at its effector surface.

(ii) Changes in the internal structure of a neuron (regardless of whether they arise selected by the autonomous transformation of the cell, or by its history of interactions in the neuronal network) by changing the domain of states of activity that the neuron can adopt, change its domain of input-output relations, that is, change its transfer function.

(iii) No single cell or class of cells can alone determine the properties of the neural network which it integrates.

Generally then, the structure of a neuron and its role in the neuronal network which it integrates does not stay invariant, but changes along its ontogeny in a manner subordinated to the ontogeny of the organism which is both a result and a source of the changes that the neuronal network and the organism undergo.

2. *Organization: The Nervous System As a Closed System*

From the descriptive point of view it is possible to say that the properties of the neurons, their internal structure, shape and relative position, determine the connectivity of the nervous system and constitute it as a dynamic network of neuronal interactions. This connectivity, that is, the anatomical and operational relations which hold between the neurons which constitute the nervous system as a network of lateral, parallel, sequential and recursive inhibitory and excitatory interactions, determines its domain of possible dynamic states. Since the properties of the neurons change along the ontogeny of the organism, both due to their internal determination and as a result of their interactions as components of the nervous system, the connectivity of the nervous system changes along the ontogeny of the organism in a manner recursively selected during this ontogeny. Furthermore, since the ontogeny of the organism is the history of its autopoiesis, the connectivity of the nervous system, through the neurons which constitute it, is dynamically subordinated to the autopoiesis of the organism which it integrates.

Operationally, the nervous system is a closed network of interacting neurons such that a change of activity in a neuron always leads to a change of activity in other neurons, either directly through synaptic action, or indirectly through the participation of some physical or chemical intervening element. Therefore, the organization of the nervous system as a finite neuronal network is defined by relations of closeness in the neuronal interactions generated in the network. Sensory and effector neurons, as they would be described by an observer who beholds an organism in an environment, are not an exception to this because all sensory activity in an organism leads to activity in its effector surfaces, and all effector activity in it leads to changes in its sensory surfaces. That at this point an observer should see environmental elements intervening between the effector and the sensory surfaces of the organism, is irrelevant because the nervous system is defined as a network of neuronal interactions by the interactions of its component neurons regardless of intervening elements. Therefore, as long as the neural network closes on itself, its phenomenology is the phenomenology of a closed system in which neuronal activity always leads to neuronal activity. This is so even though the ambience can perturb the nervous system and change its status by coupling to it as an independent agent at any neuronal receptor surface. The changes that the nervous system can undergo without disintegration (loss of defining relations as a closed neuronal network) as a result of these or any other perturbation are fully specified by its connectivity, and the perturbing agent only constitutes a historical determinant for the concurrence of these changes. As a closed neuronal network the nervous system has no input or output, and there is no intrinsic feature in its organization which would allow it to discriminate through the dynamics of its changes of state between possible internal or external causes for these changes of state. This has two fundamental consequences:

(i) The phenomenology of the changes of state of the nervous system is exclusively the phenomenology of the changes of state of a closed neuronal network; that is, for the nervous system as a neuronal network there is no inside or outside.

(ii) The distinction between internal and external causes in the origin of the changes of state of the nervous system can only be made by an observer that beholds the organism (the nervous system) as a unity, and defines its inside and outside by specifying its boundaries.

It follows that it is only with respect to the domain of interactions of the organism as a unity that the changes of state of the nervous system may have an internal or an external origin, and, hence, that the history of the causes of the changes of state of the nervous system lies in a different phenomenological domain than the changes of state themselves.

3. *Change*

Any change in the structure of the nervous system arises from a change in the properties of its component neurons. What change in fact takes place, whether morphological or biochemical or both, is irrelevant for the present discussion. The significant point is that these changes arise in the coupling of the nervous system and the organism through their homeostatic operation subordinated to the autopoiesis of the latter. Some of the changes directly affect the operation of the nervous system because they take place through its working as a closed network; others affect it indirectly because they take place through the biochemical or genetic coupling of the neurons to the organism and change the properties of the neurons in a manner unrelated to the actual working of the network. The results are twofold: on the one hand, all changes lead to the same thing, that is, changes in the domain of possible states of the nervous system; on the other hand the nervous system is coupled to the organism both in its domain of interactions and in its domain of internal transformations.

4. *Architecture*

The connectivity of the nervous system is determined by the shapes of its component neurons. Accordingly, every nervous system has a definite architecture determined by the kinds and the numbers of the neurons which compose it; therefore, members of the same species have nervous systems with similar architectures to the extent that they have similar kinds and numbers of neurons. Conversely, members of different species have nervous systems with different architectures according to their specific differences in neuronal composition. Therefore, the closed organization of the nervous system is realized in different species in different manners that have been determined through evolution; in all cases, however, the following conditions are satisfied:

(i) Since, due to its constitution as a network of lateral, parallel, sequential and recursive interactions, the nervous system closes on itself at all levels, the mutilations that it may suffer generally leave a closed neuronal network with a changed architecture. Accordingly, the organization of the nervous system is essentially invariant under mutilations, while its domain of possible states, which depends on its structure, and, hence, on its architecture, is not. Yet, due to its closed organization, whatever is left of the neural network after a partial ablation necessarily operates as a different whole with different properties than the original, but not as a system to which some of its properties have been selectively subtracted.

(ii) There is intrinsically no possibility of operational localization in the nervous system in the sense that no part of it can be deemed responsible for its operation as a closed network, or for the properties which an observer can detect in its operation as a unity. However, since every nervous system has a definite architecture, every localized lesion in it necessarily produces a specific disconnection between its parts and, hence, a specific change in its domain of possible states.

(iii) The architecture of the nervous system is not static, but it becomes specified along the ontogeny of the organism to which it belongs, and its determination, although under genetic control, is bound to the morphogenesis of the whole organism. This has two implications: (a) the variability in the architecture of the nervous system of the members of a species is determined by individual differences in genetic constitution and ontogeny; (b) the range of permissible individual variations (compatible with the autopoiesis) is determined by the circumstances in which the autopoiesis of the organism is realized.

(iv) The architecture of the nervous system and the morphology of the organism as a whole define the domain in which the ambience can possibly couple on the organism as a source of its deformations. Thus, as long as the architecture of the nervous system and the morphology of the organism remain invariant, or as long as there are aspects of them which remain unchanged, there is the possibility of recurrent perturbations as recurrent configurations of the ambience which couple in the same way on the nervous system and the organism.

5. *Referential States*

There are states of the nervous system which, as referential states, define subdomains of the possible states that the nervous system (and the organism) can adopt under perturbations as matrices of possible internal relations. As a result when the nervous system is in different referential states it compensates the same perturbations (characterized as configuration of the ambience) following different characteristic modes of change. Emotions, sleep, wakefulness, are referential states. In the dynamics of the nervous system, referential states are defined as are all other states of the nervous system, that is, by relations of neuronal activity, and as such are generated by change of neuronal activity and generate changes of neuronal activity. What is peculiar to them is that they constitute states on which other states can be inserted as substates in the process of generating the autopoiesis of the organisms. Therefore, their distinction lies in the domain of observation because for the nervous system they are part of their dynamic of state to state operations, and in the domain of observation they constitute independent phenomenological dimensions.

B. CONSEQUENCES

1. *Historical Coupling*

Due to its coupling with the organism the nervous system necessarily participates in the generation of the relations which constitute the organism as an autopoietic unity. Also due to this coupling the structure of the nervous system is necessarily continuously determined and realized through the generation of neuronal relations internally defined with respect to the nervous

system itself. As a consequence, the nervous system necessarily operates as an homeostatic system that maintains invariant the relations which define its participation in the autopoiesis of the organism, and does so by generating neuronal relations which are historically determined along the ontogeny of the organism through its participation in this ontogeny. This has the following implications:

(i) The changes that the nervous system undergoes as an homeostatic system while compensating the deformations that it suffers as a result of the interactions of the organism (itself an homeostatic system), cannot be localized to any singular point in the nervous system, but must be distributed along it in a non-random manner because any localized change is itself a source of additional deformations that must be compensated with further changes. This process is potentially endless. As a result, the operation of the nervous system as a component of the organism is a continuous generation of significant neuronal relations, and all the transformations that it may undergo as a closed neuronal network are subordinated to this. If as a result of a perturbation the nervous system fails in the generation of the significant neuronal relations for its participation in the autopoiesis of the organism, the organism disintegrates.

(ii) Although the organism and nervous system are closed atemporal systems, the fact that the structure of the nervous system is determined through its participation in the ontogeny of the organism makes this structure a function of the circumstances which determine this ontogeny, that is, of the history of interactions of the organism as well as of its genetic determination. Therefore, the domain of the possible states that the nervous system can adopt as an atemporal system is at any moment a function of this history of interactions and implies it. The result is the coupling of two constitutively different phenomenologies, the phenomenology of the nervous system (and the organism) as a closed homeostatic system, and the phenomenology of the ambience (including the organism and the nervous system) as an open non-homeostatic system which thus braid together in a manner such that the domain of the possible states of the nervous system continuously becomes commensurate with the domain of the possible states of the ambience. Furthermore, since all states of the nervous system are internal states, and the nervous system cannot make a distinction in its process of transformation between its internally and externally generated changes, the nervous system is bound to couple its history of transformations to the history of its internally determined changes of state as much as to the history of its externally determined changes of state. Thus the transformations that the nervous system undergoes during its operation are a constitutive part of its ambience.

(iii) The historical coupling of the nervous system to the transformations of its ambience, however, is apparent only in the domain of observation, not in the domain of operation of the nervous system which remains a closed homeostatic system in which all states are equivalent to the extent that they all lead to the generation of the relations which define its participation in the autopoiesis of the organism. The observer can see that a given change in the structure of the nervous system arises as a result of a given interaction of the organism, and he can consider this change as a representation of the circumstances of the interaction. The representation, however, as a phenomenon exists only in the domain of observation and has a validity that applies only in the domain generated by the observer as he maps the environment on the behaviors of the organism by treating it as an allopoietic system. The referred change in structure of the nervous system constitutes a change in the domain of its possible states under conditions in which the representation of the causing circumstances do not enter as a component.

2. *Learning as a Phenomenon*

If the connectivity structure of the nervous system changes as a result of some interactions of the organism, the domain of the possible states which it (and the organism) can henceforth adopt, changes; as a consequence, when the same or similar conditions of interaction recur, the dynamic states of the nervous system and, therefore, the way the organisms attains autopoiesis are necessarily different from what they would have otherwise been. Yet, that the conduct of the organism under the recurrent (or new) conditions of interaction should be autopoietic and, hence, appear adaptive to an observer, is a necessary outcome of the continuous homeostatic operation of both the nervous system and the organism. Since this homeostatic operation continuously subordinates the nervous system and the organism to the latter's autopoiesis in an internally determined manner, no change of connectivity in the nervous system can participate in the generation of behavior as a representation of the past interactions of the organism: representations belong to the domain of descriptions. The change in the domain of the possible states that the nervous system can adopt, which takes place along the ontogeny of the organism as a result of its interactions, constitutes learning. Thus, learning as a phenomenon of transformation of the nervous system

associated to a behavioral change that takes place under maintained auto poiesis, occurs due to the continuous dynamic coupling of the state-deter mined phenomenology of the nervous system and the state-determine phenomenology of the ambient. The notions of acquisition of representation of the environment or of acquisition of information about the environment i relation to learning, do not represent any aspect of the operation of th nervous system. The same applies to notions such as memory and recall which are descriptions made by the observer of phenomena that take place i his domain of observation, and not in the domain of operation of the nervou system, and, hence, have validity only in the domain of descriptions, wher they are defined as causal components.

3. *Time as a Dimension*

Any mode of behavioral distinction between otherwise equivalent inter actions, in a domain that has to do with the states of the organism and no with the ambience features which define the interaction, gives rise to referential dimension as a mode of conduct. This is the case with time. It i sufficient that as a result of an interaction (defined by an ambience con figuration) the nervous system should be modified with respect to the specifi referential state (emotion of assuredness, for example) which the recurrenc of the interaction (regardless of its nature) may generate for otherwis equivalent interactions to cause conducts which distinguish them in a dimen sion associated with their sequence, and, thus, give rise to a mode of behavio which constitutes the definition and characterization of this dimension Therefore, sequence as a dimension is defined in the domain of interaction of the organism, not in the operation of the nervous system as a close neuronal network. Similarly, the behavioral distinction by the observer o sequential states in his recurrent states of nervous activity, as he recursivel interacts with them, constitutes the generation of time as a dimension o the descriptive domain. Accordingly, time is a dimension in the domain o descriptions, not a feature of the ambience.

C. IMPLICATIONS

Since history as a phenomenon is accessible to the observer only in th domain of descriptions, it is only in this domain that history may participat in the generation of the observer's behavior. This, in fact, takes place. Descrip tions as linguistic behavior constitute a source of deformations of the nervou system and, hence, part of its ambience. Accordingly, the phenomenology of transformation of the nervous system discussed above also applies to the interactions of the organism in the domain of descriptions, and the structure of the nervous system is also a function of the history of interactions of the organism in this domain. The implications are obvious. The operation of the nervous system makes no distinction between its different sources of deformation, and, accordingly, it makes no difference with respect to this operation whether the deforming agents are physical environmental features or behavioral interactions with coupled organisms. Therefore, although the nervous system operates in a state-to-state fashion, time as a mode of behavior enters in the determination of its states through the descriptive domain as a component in the domain of behavior of the organism. The same occurs with any other component of the domain of descriptions which even though they do not represent states of the nervous system they act, as any behavior, as selectors of its path of structural change. This is so even with notions like *beauty*, *freedom* and *dignity* which, as descriptions arise in the domain of behavior of the organism through distinctions referred to it as a result of the coupling of the phenomenology of the nervous system as a closed neuronal network and the domain of interactions of the organism.

We have not given a formal description of the nervous system in the language of anatomy or electrophysiology because our purpose was to disclose the organization of the nervous system as a closed neuronal network, and the languages of neurophysiology and anatomy through their references to function and input and output relations imply the notion of an open system. The distinction is significant because the disclosure of the organization of the nervous system as that of a closed neuronal network leads to a fundamental notion:

The correspondence that the observer sees between the conduct of the organism and the environmental conditions with which this conduct appears to cope, reveals the structural coupling of the organism (nervous system included) to its ambience as this structural coupling is conserved through philogenic and ontogenic selection. This correspondence, therefore, does not reveal any particular feature or property of the connectivity of the nervous system that would permit it to operate with representations of the ambience in its computation of the adequate conduct of the organism.

GLOSSARY

This glossary only contains words that in this work are given a specifi meaning or words that are new. All the definitions are direct quotations fron the text.

ALLOPOIETIC MACHINE: machines that have as product of their func tioning something different from themselves, as in a car.

AUTONOMY: the condition of subordinating all changes to the maintenanc of the organization. Self-asserting capacity of living systems to maintai their identity through the active compensation of deformations.

AUTOPOIETIC MACHINE: a machine organized (defined as a unity) as network of processes of production, transformation and destruction o components that produces the components which: (i) through their inte actions and transformations regenerate and realize the network of processe (relations) that produced them; and (ii) constitute it as a concrete unity i the space in which they exist by specifying the topological domain of it realization as such a network.

AUTOPOIETIC SPACE: an autopoietic organization constitutes a close domain of relations specified only with respect to the autopoietic or ganization that these relations constitute, and thus it defines a space i which it can be realized as a concrete system, a space whose dimension are the relations of production of the components that realize it.

BIOLOGICAL EXPLANATION: a reformulation in terms of processe subordinated to autopoiesis, that is, a reformulation in the biologica phenomenological domain.

BIOLOGICAL PHENOMENON: the biological phenomenology is the phe nomenology of autopoietic systems in the physical space and a phenomeno is a biological phenomenon only to the extent that it depends in one wa or another on the autopoiesis of one or more physical autopoietic unities

CODING: A notion which represents the interactions of the observer, not phenomenon operative in the observed domain. A mapping of a proces that occurs in the space of autopoiesis onto a process that occurs in th space of human design (heteropoiesis) and, thus, not a reformulation o the phenomenon.

COGNITIVE DOMAIN: the domain of all the interactions in which an autopoietic system can enter without loss of identity.

COMMUNICATIVE DOMAIN: a chain of interlocked interactions such that although the conduct of each organism in each interaction is internally determined by its autopoietic organization, this conduct is for the other organism a source of compensable deformations.

COUPLING (OF UNITIES): whenever the conduct of two or more unities is such that the conduct of each one is a function of the conduct of the others.

DIVERSITY: variations in the mode in which identity is maintained.

EVOLUTION: history of change in the realization of an invariant organization embodied in independent unities sequentially generated through reproductive steps, in which the particular structural realization of each unity arises as a modification of the preceding one (or ones) which, thus, constitutes both its sequential and historical antecedent.

EXPLANATION: a reformulation of a phenomenon in such a way that its elements appear operationally connected in its generation.

FUNCTION: notion that arises in the description made by the observer of the components of a machine or system in reference to an encompassing entity, which may be the whole machine or part of it and whose states constitute the goal that the changes in the components are to bring about.

HETEROPOIESIS: the space of human design.

HISTORICAL PHENOMENON: a process of change in which each state of the successive states of a changing system arises as a modification of a previous state in a causal transformation and not *de novo* as an independent occurrence.

HOMEOSTATIC MACHINES: the condition of maintaining constant or within a limited range of values some of their variables.

INDIVIDUALITY: maintenance of identity by an autopoietic machine independently from its interactions with an observer.

LINGUISTIC DOMAIN: a consensual domain in which the coupled organisms orient each other in their internally determined behavior through interactions that have been specified during their coupled ontogenies.

MACHINE: a unity in the physical space, defined by its organization, which connotes a non-animistic outlook, and whose dynamisms is apparent.

MACHINE, PURPOSE OR AIM OF: the use to which a machine can be put by man, sometimes its product. A descriptive device to reduce the task of conveying to a listener the organization of a particular machine.

MECHANICAL PHENOMENOLOGY: the phenomenology generated by

relations between processes realized through the properties of components.

MECHANICISM: a biological outlook which asserts that the only factors operating in the organization of living systems are physical factors, and that no non-material vital organizing force is necessary.

OBSERVER: a system that through recursive interactions with its own linguistic states may always linguistically interact with its own states as if with representations of its interactions.

ONTOGENY: the history of the structural transformations of a unity.

ORGANIZATION: the relations that define a system as a unity, and determine the dynamics of interaction and transformations which it may undergo as such a unity, constitute the organization of the system.

PHENOMENOLOGICAL DOMAIN: defined by the properties of the unity or unities that constitute it, either singly or collectively through their transformations or interactions. Thus whenever a unity is defined or a class of unities is established which can undergo transformations or interactions a phenomenological domain is defined.

PHYSICAL SPACE: the space within which the phenomenology of autopoiesis of living systems takes place.

PURPOSE: the possession of an internal project or program represented and realized through the components of a unity.

REGULATION: a notion valid in the domain of description of heteropoiesis that reflects the simultaneous observation and description made by the designer (or its equivalent) of interdependent transitions of the system that occur in a specified order and at specified speeds.

RELATIONS OF CONSTITUTION: determine that the components produced constitute the topology in which the autopoiesis is realized.

RELATIONS OF ORDER: determine that the concatenation of the components in the relations of constitution, specification and order be the ones specified by the autopoiesis.

RELATIONS OF SPECIFICITY: determine that the components produced be the specific ones defined by their participation in the autopoiesis.

REPRODUCTION: any of the processes of replication, copying or self reproduction.

SELECTION: a process of differential realization of a production of unities in a context that specifies the unitary organization that can be realized. In a population of autopoietic unities, selection is a process of differential realization of autopoiesis, and hence, of differential self-production.

SELF-CONSCIOUSNESS: the domain of self-observation.

SELF-REPRODUCTION: when a unity produces another with a similar organization to its own, through a process that is coupled to the process of its own specifications. Only autopoietic systems can self-reproduce.

SPECIES: a population or collection of populations of reproductively interconnected individuals which, thus, are nodes in a historical network.

STATICAL PHENOMENOLOGY: the phenomenology generated by the relations between properties of components.

STRUCTURE: the actual relations which hold between the components which integrate a concrete machine in a given space.

SYSTEM: any definable set of components.

TELEONOMY: the element of apparent purpose or possession of a project in the organization of living systems, without implying any vitalistic connotations. Frequently considered as a necessary if not sufficient definitory feature of the living organization.

UNITY: that which is distinguishable from a background, the sole condition necessary for existence in a given domain. The nature of a unity and the domain in which the unity exists are specified by the process of its distinction and determination; this is so regardless of whether this process is conceptual or physical.

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