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Structure

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1. The Various Meanings of the Term "Structure"

Derived from the Latin verb *struere* 'to construct,' the term *structure* is lexically synonymous with *construction, composition, ordering,* in short with *organization,* and essentially refers to the system of connections which "organically" link up parts within an organized whole. As such, it occurs in many domains as a more or less technical term: the structure of a building or of an urban zone, the structure of a mechanism, the structure of a work of art, judicial and social structures, the structure of a firm, the structure of a biological organism, the structure of a molecule or of a macromolecule, the structure of a physical milieu, of a crystal, of a stellar object, of a texture, the structure of a sentence, of a narrative, of a myth, the structure of a phonological system, the structure of perception, cognitive structures, kinship structures, the structures of the imaginary, etc. However, according to the domain considered, the term can have a very different problematical content and epistemological value. In the case of a technical mechanism, a construction or a work of art, one generally knows how to describe the structure of the whole by means of a plan of composition. In the case of physico-chemical systems (crystals, macromolecules, etc.) one also knows (at least in principle) how to derive the structure from the interactions between components. For example, spectacular progress in molecular biology and in microbiology has enabled a decisive breakthrough in the understanding of the structure (the stereo-chemical morphology) of the DNA chains, of proteins, of enzymes, of membranes, etc. Of course, experimental difficulties are considerable. To resolve them one must apply to highly sophisticated technologies of observation and reconstruction techniques. But by right, even if the structure is not completely mistaken for the morphology observed, even if the former is made the organizational principle of the latter, one is nonetheless in the presence of phenomena and material objects whose *ontological* status is non-problematical.

In other domains, on the other hand, such as, for example, in natural biology (taxonomic, anatomic, morphogenetic, that is not strictly physico-chemical), in perception, in anthropology or in semiolinguistics, one comes up against *immanent non-material* structures, against abstract forms of organization which seem irreducible to systems of interacting components. This simple fact raises considerable theoretical problems insofar as structures, without further inquiry, can no longer be considered as objects of experience having a *pre-defined* ontological status. The *objectivity* of the structures therefore must be *constituted* as such, and that is why, in every one of the cited cases, in an effort to get to the bottom of things, it has been necessary (1) to make the organizational concept of structure an authentic comprehensive and explanatory *category,* (2) to critically interrogate its *objective value* and (3) to attempt to *formalize* its categorical semanticism. This is how the new methodology and new rational unity called *structuralism* have been progressively developed.

In the natural descriptive sciences, as well as in the human sciences, the theory and the formalization of structuralism are based on a *rationalist* attitude. Its point of view is opposed to that of reductionist "atomism" as well as that of evolutionary historicism. The passage from atomistic psychology to *Gestalt[1] theory, from the neogrammarians' historical, comparative and philological linguistics to Saussure's structural linguistics, from "behaviorist" linguistics to Chomsky's generative grammars, from biographical and sociopsychological literary criticism to structural criticism, etc., represents various aspects of a general theory of *systems* conceived as (self)-regulated totalities. From this perspective the horizon of structuralism is that of the *phenomenological description*—and then of the formalization—of the *a priori* constraining the *formal* relations of *dependency* linking—"organically" and systematically—parts in wholes.

Thus, concerned with the general dialectic of parts and wholes, structuralism, in one way or another, and this irrespective of the aspect considered, is indeed concerned with the relation between substance and form, and so with the Greek problematics of *morphe, eidos,* and *ousia*.

As the ideal *form* of the organization of a substance, structure *is not a perceptible phenomenon*. As such it is "invisible," though its substantial realization and its effects can be clearly experimentally observed and analyzed. This is why every structure is a *theoretical object* (and not a fact), a theoretical object which is at the same time *ideal and real* (Paraphrasing what Kant said about space and time as forms of intuition, one could say that

[1] Terms preceded by an asterisk are correlates.

the object "structure" has both empirical reality and transcendental ideality.) If naive idealism is to be avoided, the difficulty is therefore to *understand how it can emerge, by a process of morphogenesis, from the organization of the substratum where it is realized.* This is in a way the "founding aporia" (to refer back to René Thom's expression), of all structuralisms. This is what Deleuze insists on: "real without being actual, ideal without being abstract," pure "virtually of coexistence which preexists things," (1973: 313), a structure "is embodied" in its substratum, is "expressed" in it, but is never actualized as such in it. The perceptible expression of a structure is always, in essence, the negation of its formal being. As Pomian writes:

> "This is why, for the object as it initially appears, two objects, whose ontological status is different from that of the first one, are, while remaining different from each other, substituted [in every structural approach]: speech and language (Saussure), sounds and phonemes (Jakobson, Trubetskoi), substance and form (Hjelmslev), kinship systems and elementary structures (Lévi-Strauss), performance and competence (Chomsky), empirical morphologies and underlying dynamics (Thom) are examples of this. All of the first terms of these couplings (which can be called "realizations") can be reached by means of perceptual experience or by observation, and this is in what their reality consists of. As far as the second terms are concerned (except for Saussure's language, to be exact: system, or the function of structure, is taken up by the "mechanism of limitation of arbitrariness") structures, by definition, cannot be perceived or observed. They are given a reality by means of demonstration, which is, according to the case, more or less rigorous. Relations between realizations and structures are variable but it is always the latter which make the former stable and intelligible. This leads to the following definition of the notion of structure: sets of rational and interdependent relations whose reality is demonstrated, whose description is given by a theory and which are realized by a visible or observable object whose stability and intelligibility they insure. (1981: 758)"

Because of their ideal status, which is nonphenomenal in the classical sense (perceptible) of the term, structures are therefore *ontologically ambiguous.* As Eco asks:

> "Is the structure an object, insofar as it is structured, or is it the set of relations which structures the object but which can be abstracted from the object?"

(1972c: 322). As eidos, a structure cannot be detached from the substance in which it is actualized, from the ousia where it becomes substance. It is at the same time intelligible framework and structured object. (Eco 1972c: 323)"

But must it be considered *as given* or *posited*? In the first case an *ontological* (realist) conception of structure will be developed, and, in the second case, an *epistemological* (nominalist) one.

The influence exercised on the contemporary episteme by positivism and logical empiricism, through their systematic will to eradicate the ontological question from the theory of knowledge, has lead to a privileging of the epistemological interpretation by reducing the concept of structure to a mere metalinguistic operational one whose reality is non-ontological but purely methodological. Yet, it should be noted here that all of the "great" structuralists (Saussure, Jakobson, Tesnière, Hjelmslev, Piaget, Lévi-Strauss, Chomsky, Greimas, and Thom) were, or are, "realists" even if they refuse to get involved in philosophical dispute. In addition, realism in no way claims to detain the "final" say about phenomena but simply affirms the need for the theoretization of phenomena (and in particular their formalization) to be in agreement with the "thing itself." Finally, as such, realism is the only rational position able to transform the concept of structure into an *explanatory* concept, that is to say into a *category* of experience.

Indeed, from an epistemological, methodological, and "nominalist" perspective, the concept of structure can be only a *descriptive* concept which, although empirically founded, is *without proper objective value*. Although operational, it is then only an intellectual artifact (a metalinguistic construct) and cannot therefore become the source of an authentic theoretical progress. In particular, it cannot lead to progress *in the mathematization* of phenomena. From a realist perspective, on the contrary, it becomes a theoretical object which, although initially problematical, must acquire, beyond its empirical validity, a categorical content, an objective value and a constitutive thrust. Since it does not subsume perceptible phenomena it therefore leads to new and fundamental problems. First it leads to a re-examination of the transcendental problematics (Kantian, Husserlian) of the *constitution of objectivities* so that (1) one can found *rationally* the new class of phenomena (non-perceptible) which are the structural phenomena, and (2) one can determine the ontological thrust of the category of structure. Next, and perhaps especially, for an "authentic" formalization of the former, it leads to the substitution of an *adequate and explicitly constructed mathematical content* for the semanticism of the latter. This last requirement

meets with considerable difficulties which until now were insurmountable. It is dramatically lacking in purely epistemological perspectives.

If one wished to undertake a "spectral analysis" of structuralism, either historically or systematically, it would be necessary to analyze at least the following trends and their interferences.

(1) Dynamical structuralism, of biological origin and of vitalistic nature, which, beginning with *Naturphilosophie* and *Dynamismus* in German speculative idealism, has cut across the history of biology before leading up to Waddington's concepts of "morphogenetic field" and "chreod." This dynamical structuralism centers upon the outstanding problem of *morphogenesis*.

(2) Phenomenological and Gestalt structuralism, which was elaborated at the beginning of the century from the works of Brentano (Stumpf, Meinong, Ehrenfels, Husserl, Köhler, Koffka, Wertheimer, etc.).

(3) Linguistic structuralism which, stemming from the Saussurean "epistemological rift," became one of the fundamental paradigms of the human sciences whether in phonology, with Jakobson, in anthropology, with Lévi-Strauss, or in linguistics, with Chomsky. This structuralism itself split up into two streams, (3a) phenomenological "realist" structuralism (linked to Jakobson) which bears a close relationship to dynamic structuralism and Gestalt theory; and (3b) formal, "methodological" and "epistemological" structuralism (linked to Hjelmslev, Lévi-Strauss, Chomsky, and Greimas) which considers structures as "axiomatizable" theoretical objects and resolves the question of their ontological reality by rooting them in biologically (therefore genetically) determined cognitive capacities.

(4) Piaget's epigenetic and cognitive structuralism.

(5) "Morphodynamical" structuralism developed by René Thom. This one (last but not least) is an original and fundamental synthesis of the concepts of morphogenesis and structure, and therefore of "vitalistic" dynamical structuralism and semiolinguistic rationalism begun with Saussure. Thom is the first to have succeeded in mathematizing, in a sophisticated manner and according to the "things themselves," structures as theoretical objects. As such, his contribution constitutes an authentic renaissance of structural thought, and leads to recasting it on radically new, mathematical bases.

In order to be more or less complete, it would also be necessary to make explicit a number of general problematics indissolubly linked to the rationalist structural project. Among these, five seem to be essential.

(1) That of *experimental methods* making the access to structures possible: Since these are immaterial and ideal they cannot be directly observed. A first method of access (that, for example, advocated by Lévi-Strauss) consists in analyzing by *variational* procedures the: *transformations* of a structure. If indeed this latter can be identified with the global, internal, and regulated cohesion of a system of relations, then all local variations must bring about global transformations which *manifest* the structure. A second method (that, for example, of Chomsky's "native speaker," conceived as an automaton receiver of language) consists in submitting old introspective practices to experimental control.

(2) That of the relation between structure and *function*. Indeed the latter is the *raison d'être* and adaptive signification of the former. Since the historical debate between Geoffroy Saint-Hilaire's principle of connection and Cuvier's principle of functional correlation, a natural dialectic opposes, in secular misunderstanding, two complementary aspects of the same reality. As the author of the article "Structure and Function" in the *Encyclopaedia Universalis* brings up, this dialectic opposes to a naturalistic attitude (a) inspired from a vitalistic holistic conception, (b) based on observation, (c) founded on morphogenesis, and (d) linked to Lamarck, a strictly biological, mechanistic, and materialistic attitude (a) drawing upon a "micromeric" conception, (b) stemming from active experimentation, (c) focusing upon physiology and (d) of essentially Neo-Darwinian inspiration. But the debate is rather fallacious, since phenomena of adaptation (and in particular those of adaptive convergence and parallel evolution) show that there exists an irreducible correlation between these two aspects (cf. Delattre *et al.* 1973). The problem is rather—and it is a most formidable one at that—to reach a *theoretical* comprehension of this correlation.

(3) That of the relation between structure and *finality:* One of the main reasons for the disfavor that the concept of structure fell into is that, dealing with the general problem of the systematic organization of the parts in a whole, for a very long time it covered only a finalistic content (a ideological idea) and could be expressed only by the vitalistic concept of *entelechy*. Before becoming an operational scientific concept, it had therefore to be "definalized." This was only possible through formalization.

(4) That, precisely, of the *formalization* of structures: It has become commonplace to say that it is the combined development of the general theory of systems, of cybernetics, and of a

formal logic of interdependency relations, which, by favoring the "axiomatization" of the concept of structure, established its claim as science. But one must recognize that these mechanistic and formalist approaches are quite inadequate. Indeed, they are possible only if the structures are *reified* beforehand and do not agree any more with the "thing itself." They do not permit an accounting for immaterial structures as organized and self-regulated forms emerging epigenetically from the material structure of their substrata. In other words, they do not help to resolve the traditional question of the relation between form and substance. As such, the problem of the formalization of structures is still largely open and has begun partially to be solved only by means of catastrophe theory.

(5) That of *levels of organization*: The correlation structure-function operates at every level of integration and observation. The central question therefore becomes that of the definition of the objective reality of these levels as well as the understanding of their hierarchical dependency and, at the same time, of their autonomy.

These points will be raised here in an extremely lacunary fashion. In particular, "classical" structuralism, which has become part of common scientific culture, will not be accentuated (Saussurean structuralism, Parsons' structural-functionalism, Bloomfield's, Harris,' and Chomsky's structural linguistics, the structural analysis of economic equilibria etc.). For an introduction to structuralism, see, for example, in addition to the works cited here: Almansi 1970; Bach 1965; Badcock 1975; Barthes 1966a; Bastide 1962; Benoist 1975; Benveniste 1966a; R. Boudon 1968, 1973, 1981; Broekman 1974; Cassirer 1946c; Chomsky 1965, 1966a, 1968a; Damisch 1973; Delattre 1971; Ducrot et al. 1973; Eco 1963; Ehrmann 1966; Gandillac, Goldmann, and Piaget 1965; Gluckmann 1974; Greimas 1966a; Harris 1951, 1970; Hawkes 1977; Hjelmslev 1968, 1971; Jacob and Francone 1970; Jakobson 1971j; Jakobson and Lévi-Strauss 1962; Katz and Fodor 1963; Laughlin 1974; Leach 1976; Lévi-Strauss 1949; Macksey and Donato 1970; Maranda and Maranda 1971a; Marin 1977; Raccani and Eco 1969; Robey 1973; Saussure 1916; Sebag 1964; Sebeok and Osgood 1965b; Segre et al. 1965; Viet 1965.

We prefer to emphasize: (1) the *theoretical* difficulties, still largely unresolved, of structuralism; (2) its unpopular aspects, whether phenomenological, or vitalistic, or Gestaltist; and (3) the content and contribution of the new "revolution" brought about by the catastrophic paradigm.

However, we shall begin by saying a few words about structuralism in mathematics, since it often serves as a support to justify formalistic conceptions. For further explanation cf.

Bell and Slomson 1969; Bourbaki 1969; Dieudonné 1977, 1978; Lautman 1977; Luxembourg 1969; Machover and Hirschfeld 1969; Manin 1981; A. Robinson 1966.

2. Structuralism in Mathematics

In mathematics, the concept of structure was worked out and progressively imposed during the nineteenth century, and from the Hilbertian axiomatic project and Bourbaki's *Eléments* (1969), took modern achievements by storm. Its relevance stems from the more and more important role *abstraction* played in mathematics. For the longest time human beings reasoned on "concrete" mathematical objects which were supposedly naturally and intuitively given ("concrete" in the mathematical sense, that is to say objects which are of course ideal but *individuated:* numbers, geometric spaces, functions, equations, etc.). But it was quickly realized that, in the same way as natural language enables the conceptual analysis of concrete natural objects, so too it was necessary to develop a "conceptual" analysis of "concrete" mathematical objects as syncretisms of abstract moments.

This original "conceptual" analysis evidently cannot be simply reduced to the truism about the existence of general concepts in mathematics (the concept of triangle, polygon, polynomial, set, etc.). It is *structural* in the following sense: mathematical objects are explicitly constructed (by procedures of construction formalized first within the context of set theory, and then, more recently, within that of the theory of categories). Therefore (contrary to given, non-constructed objects), they don't present any opacity, and all of their properties are analytically contained in their construction. Demonstrations are used to make these properties explicit. But when such demonstrations are analyzed, generally one finds that only *a part of* the properties characterizing the object have been used. For example, in a demonstration bearing on the set $\boldsymbol{R}$ of real numbers, only the algebraic operations of addition and/or multiplication, or the relation of order $x \leq y$, or again the possibility of measuring distances will have been used. With Bourbaki, through abstraction, *different levels of structure* (that of algebraic structures, that of order structure, that of metric structure) will then be distinguished, and the "concrete" object will appear as a synthetically intertwining syncretism of some of them. Obviously, the choice of "good" base structures has demanded a considerable work of comparison between "concrete" objects. This work can now be considered mostly finished.

Once the fundamental concept of abstract structure and of level of structure was established through finer and finer intertwining structures, a concrete object could be specified. For example, in the case of $\boldsymbol{R}$ one can say that:

(1) As a set with the operation of addition, $\boldsymbol{R}$ is a commutative group.

(2) Multiplication being compatible with addition (i.e., distributive in relation to it), it defines a (commutative) ring structure on $\boldsymbol{R}$.

(3) Since for multiplication all non-null elements of $\boldsymbol{R}$ are inversible, $\boldsymbol{R}^* = \boldsymbol{R} - \{0\}$ is also a multiplicative commutative group. This multiplicative group structure being compatible with the additive structure, the ring $\boldsymbol{R}$ is in fact a (commutative) field.

(4) As there exists no number $x \in \boldsymbol{R}$ such that $x \neq 0$ and $nx = 0$, $\boldsymbol{R}$ is a field of characteristic zero.

(5) Provided with its natural relation or order, $\boldsymbol{R}$ is a totally ordered set.

(6) This order has the property of density, that is to say, for every pair $(x, y) \in \boldsymbol{R} \times \boldsymbol{R}$ so that $x < y$, there exists $z \in \boldsymbol{R}$ so that $x < z < y$.

(7) This order is Archimedean: for every number $x > 0$ as small as it can be and for every number $y > 0$ as large as it can be there exists a (large) integer N such that $Nx > y$.

(8) Order being compatible with the algebraic structure, $\boldsymbol{R}$ is a totally ordered Archimedean field.

(9) Since there exists a distance on $\boldsymbol{R}$, $\boldsymbol{R}$ is a metric space.

(10) For its natural metrics $\boldsymbol{R}$ is a complete metric space (i.e., "without holes" contrary to its totally ordered Archimedean subfield of rational numbers).

(11) Metrics proceeds, in fact, from order and algebraic structures, since the distance $d(x, y)$ between two numbers $x, y \in \boldsymbol{R}$ is the absolute value $|x - y|$ of their difference and since the absolute value is defined from the order and addition ($|x| = x$ if $x \geq 0$ and $|x| = -x$ *if* $x \leq 0$). Because of the compatibility between the algebraic and the order levels, it remains invariable through translation.

(12) Therefore, considered as a field and as a vectorial space on itself, $\boldsymbol{R}$ is a normed vector space and, following (10), a complete one, etc.

The importance of the structural approach to mathematical objects is considerable. Indeed, it enables us to substitute pure *formal* criteria of identity for the *substantial ones*. Two *isomorphic structures,* that is to say, indistinguishable as far as their structure is concerned, will be considered equivalent even if the elements of their underlying sets are of different types. For example, the set $\boldsymbol{P}$ of the polynomials $ax^2 + bx + c$ of second degree of a variable x with real coefficients, has a natural vector space structure over $\boldsymbol{R}$, isomorphic to $\boldsymbol{R}^3$, although such a polynomial (which is a function from $\boldsymbol{R}$ to $\boldsymbol{R}$) and a point of three dimensional space are heterogeneous entities. This approach also permits us to consider *transformations* between structures of the same type (what are called *morphisms* of the structure, of which isomorphisms are particular cases), and thus opens up onto the theory of categories. It then permits us to treat the objects *axiomatically,* which leads to those delicate problems concerning relations between syntax and semantics in the logical theory of models.

Given a structure of type S, for example the group structure, it can be considered in two ways, either syntactically or semantically. Syntactically speaking, one chooses a *formal language* L adequate to the formulation of formal expressions about S (for example a first order predicate calculus having a symbol of operation for the law of the group and a symbol of constant e for the neutral element). S is characterized in L by a finite system of axioms Σ. The theory of S relative to L will then be the deductive closure $\mathrm{Th}(\Sigma)$ of Σ in L. Semantically speaking, on the other hand, one considers in a universe U of set theory, the category (Σ) of objects having a type S structure (here the category of groups), in other words the category of the *models* of Σ. Given a model G (here a group), the set of expressions of L which become true once interpreted in G, constitute the theory $\mathrm{Th}(G)$ of G. Whereas $\mathrm{Th}(\Sigma)$ is a syntactic entity (based on the syntactic notion of deductibility or of derivation), $\mathrm{Th}(G)$ is a semantic entity (based on the semantic notion of validity). Clearly $\mathrm{Th}(\Sigma) \subset \mathrm{Th}(G)$ since every expression deduced from a valid one is valid and since expressions of Σ are by hypothesis valid in G. The ideal would then be that:

(1) in increasing Σ in Σ^1, while maintaining it *finite,* the situation $\mathrm{Th}(\Sigma^1) = \mathrm{Th}(G)$ could be reached, which means that the theory $\mathrm{Th}(G)$ of G relative to L would be *axiomatizable*;

(2) if two objects G and G' have the same theory relative to L ($\mathrm{Th}(G) = \mathrm{Th}(G')$), they would be isomorphic, which means that the theory $\mathrm{Th}(G)$ of G would be *categorical*.

As a matter of fact, this is not generally the case, and most theories are neither axiomatizable nor categorical (existence of *non-standard models)*. This is due to a collection of subtle logical phenomena whose analysis is the object of model theory (for further explanation cf. Petitot 1979a).

But without a doubt, the principal interest of the structural approach is that it enables us to reveal a *rational unity* within the diversity of mathematical theories. This is what Manin emphasized when he wrote:

> "the usefulness of this approach stems from the fact that, in diminishing the number of initial properties granted for the objects, the number of objects which satisfy them is increased and that, by freeing ourselves from the hypothesis of the particular properties of a concrete situation, we begin to perceive a deep generality and analogy between apparently independent mathematical objects. (1981: 774)"

This being true, it is necessary, however, to understand that, contrary to what is claimed by logicism (logical formalism) its transformational mechanisms and its algorithms constitute the *least important part* of the axiomatico-structural method in mathematics. For what is essential is not the syntactic form of language but rather the *qualitative and integral* characterization of a domain of objects. This point was remarkably developed by Albert Lautman:

> "Logicians of the Vienna School seem always in full agreement with Hilbert's School. However, nothing is more questionable. Following Russell, in the Logistic School an attempt is made to find the atomic constituents of all the mathematical propositions. (…) Hilbert's and his school (…) tend, on the contrary, to isolate, for each domain studied, a system of axioms such that, at the same time, a domain and the operations valid in this domain, arise from the set of conditions implied by the axioms. (…) The consideration of a purely formal mathematics must give way to the dualism of a topological structure and functional properties in relation to this structure. (…) The object studied is not the set of propositions derived from the axioms, but organized, structured, complete beings, having their own anatomies and physiologies. (…) The point of view to be retained here, is that of the synthesis of the necessary conditions and not that of the analysis of the primary notions. (Lautman 1977: 282-83)"

3. Critical Points of Structuralism

When one passes from mathematics to empirical sciences, structural methodology changes completely insofar as one is no longer dealing with explicitly constructed (ideal) objects but with natural "opaque" phenomena *(a priori* non-intelligible) which must be no longer logically but *ontologically* understood and explained. Then the problem is no longer to abstract levels of structure but to *theoretize* the *natural phenomena* of (self)organization. Then the concept of structure no longer corresponds to properties of objects but to a conceptual category whose content must be founded, whose objective value (ontological thrust) must be (transcendentally) deduced, and whose explanatory force must be legitimated. In all domains (biology, psychology, anthropology, semiolinguistics) where structure has a real empirical value and is necessary for *understanding* (if not for explaining) specific phenomena, its theoretical function is to get beyond the conflict between on the one hand, objectivist-reductionist explanations, which consider organized wholes as systems of interacting components, and, on the other hand, holistic-idealist comprehensions which consider organized wholes as amorphous' material substrata imparted with essences foreign to them. It is to make possible a *relational and epigenetic* doctrine of organization. This intention is obviously not without problems, and brings us back to one of the oldest aporia of modern scientific rationality.

3.1. The Aporia of Organization in the Kantian Critique of Teleological Judgment

One can find the origin of modern structural problematics in Kant's *Critique of Teleological Judgment,* where he deals with biological organization in terms of finality (what he called internal finality of natural ends) and shows that the theoretical comprehension of organization must, of necessity, resort to two principles, to two antinomic "maxims" of judgment. Let us briefly retrace the various steps in his argument.

(1) Granted the *a priori* structure of every possible experience, one cannot posit an objective finality in nature. Objectively speaking, nature is necessarily mechanistic. In other words, in more modern terms, reductionism is the only objectively admissible thesis.

(2) Nonetheless, it cannot be denied that there exist "natural ends" in nature, that is to say, things that are "their own cause and effect" (Kant 1790: 190),

in short organized living beings. The fundamental characteristics of these natural biological ends are, according to Kant, regulation, reproduction, and adaptation to environment (external finality).

(3) Yet, although Kant did admit that progresses in physics could lead one day to a reductionist ("mechanistic") explanation of these, he also, in a decisive remark heavy of consequences, noted that such an explanation would always be *incomplete,* and this for *a priori* reasons. Indeed it cannot account for the *contingency of the form* of organized beings. For Kant the contingency of form is a major "characteristic property" of natural ends. Being far beyond the laws of geometry and physics, form is comprehensible only in a *reflective* way by means of the rational concept (and not the category) of finality

(4) Internal finality is not only organization but also self-organization. In a natural end, there exists a reciprocal determination between the parts and the whole. A structure is not a mechanism but the effect of the *idea* of whole, which determines its systematic unity as form. Thus organization depends on the "formative force" *(bildende Kraft)* which, not being mechanically explainable, is not objective. This is why it is an "unfathomable quality," an "immeasurable abyss" where reductionism, although being the only objectively valid attitude, must *necessarily* come to grips with the holistic concept of finality. But finality is a non-determinative (non-objective) concept which is only regulatory for the faculty of reflexive judgment The maxims of judgment, respectively reductionist and holistic, are contradictory and lead to a natural "dialectic." For Kant, this conflict is not an antinomy since it only bears on *maxims;* that is to say on prescriptions which the subject must follow to gain knowledge (on heuristics for the understanding of phenomena). There is an antinomy only if, going *dogmatically* from the reflexive to the determinative, the regulatory Idea of finality is used as a constitutive concept, as an objective category. But this does not hinder the rational concept of finality, even though being transcendent relative to the faculty of determinative judgment, from being *empirically* conditioned and valid "with the same necessity for our *human faculty of judgment* as it could have if it were an objective principle. (Kant 1790: 218)"

(5) This possibility that a regulatory Idea can have for us the same value as a constitutive concept, comes essentially from the finite and the discursive (non-intuitive) nature of our understanding.

Although things seem to have drastically changed since Kant, this is in the main illusory. The epistemological obstacle brilliantly circumscribed in the *Critique of Teleological Judgment* (that is to say the impossibility of physically explaining morphogenesis, (self)organization and regulation) is still far from being resolved. Obviously, decisive and joint progress has been made. On the one hand, reductionist (molecular and neo-Darwinian) biology, and, on the other, techniques of cybernetic simulation have been at the origin of important achievements in the elucidation of such phenomena. But we are still far from understanding how stable and self-regulatory structures can *emerge* from a physico-chemical substratum. The difficulty is not so much experimental as *theoretical*. The facts are not lacking but the concepts are. It is only recently that in *elementary* (non-biological) cases, it has become possible to begin to explain how a physico-chemical substratum can spontaneously self-organize, either temporally (oscillating chemical reactions), or spatiotemporally (spatial patterns of the Belousov-Zhabotinsky reaction, Bénard cells, etc; cf., e.g., Prigogine 1980). For this it necessary to use deep and sophisticated mathematical progress in the analysis of bifurcations of non-linear dynamical systems (cf. below). From this point of view, biology still truly remains, as Piaget affirmed (1968), "the key to structuralism."

3.2. Structuralism in Biology

In biology, the dynamical aspect of the structuralist paradigm imposed itself several times, in fact every time the problem of *morphogenesis* arose. But it has always been linked with the speculative, vitalistic concept of *entelechy,* which explains its rejection by tenants of the reductionist paradigm.

It all begins with the principle of *spatial connection* of parts in an organic whole, a principle introduced by Geoffroy Saint-Hilaire and then taken up by Goethe. In his long and patient meditation on vegetal morphogenesis between 1770 and 1832, Goethe did not attempt to understand the physico-chemical and mechanistic processes underlying the formation of organisms but rather *the principle by which an organism is what it appears to be*. He quickly came to the conclusion that what separates organisms from machines is that, in the case of an

organism, the external appearance is dominated by an *internal* principle producing the spatial (external) connection of its parts. The understanding of this principle constituted for him the central theoretical problem of biology. Yet, although rooted in indisputable empirical realities, the concept of connection is only, as we have seen with Kant, a "suprasensible," "noumenal" *idea* (and not a determinative concept, a category). Resolutely transgressing the argument of the third *Critique,* Goethe nonetheless hypothesized that there existed a *scheme* for it with infinite possible concrete variations. Instead of making this scheme, which is what Darwin did later on, the result of evolutionary chance, he attempted to imagine its characteristics. To understand the organisms' reactions to internal and external pressures, he attempted to understand their ideal constituting principle, in other words their *formative laws*. He progressively recognized this principle in the *spatiotemporal unfolding of an internal organizing force taking on existence by the very act of manifesting itself spatiotemporally*. Such is the *a priori entelechic principle* which according to Goethe commands the formation of "natural ends." But one of the central results of the Kantian critique is precisely that an Idea is by essence irremediably *dissociated* from the pure intuitions of space and time. Goethe therefore had to transgress the Kantian doctrine of objectivity and to think of entelechy as an *intuitive concept*. Whereas in physics the concept is abstracted from the perceptible world and permits only discursive expression, here the concept is self-determining. Its unity gives itself its own form. It is no longer abstract but, like Hegel's concept, *real, concrete, and perceptible*. Such is entelechy: an intuitive concept and an efficacious idea, which, by unfolding itself spatiotemporally, governs morphogenesis.

Goethe's response to the aporia of form in biology was therefore *speculative*. It was at the origin of vitalism. Yet it nonetheless possesses an eminent epistemological value insofar as the *whole* of dynamical structuralism (whether in biology, in psychology, or in semiolinguistics) has remained more or less implicitly bound to it. To see this better, first in the case of biology, we can apply to a defense of structuralism proposed by the biologists Brian Goodwin and Gerry Webster (1981, 1982) in the Waddingtonian style (Waddington 1956, 1957).

Goodwin and Webster analyze historically and epistemologically the classical and recurring conflict between the structuralist and Neo-Darwinian points of view (the latter being a synthesis of the Darwinian theory of evolution and of the molecular theory of heredity). For them structuralism is opposed to Neo-Darwinian historical empiricism not at the level of facts, but as a *rationalism* according to which *a priori* concepts, categories, and principles control the theoretical explanation of empirical data. The central problem they raise is that of

morphogenesis, and they seek the *type* of categoriality necessary to render the concept of form intelligible. Indeed, the Neo-Darwinian paradigm is a conceptual system whose apparent "evidence" precisely renders *unintelligible* morphological phenomena. It attributes these merely to evolutionary chance and negates any necessity in the order of form, any "laws" of form.

This is essentially due to the fact that, in this paradigm, the concept of *control* and the category of *cause* are surreptitiously identified. The genome controls form and development. Its mastery and its control therefore enable the control of its effects. But this does not imply the nonexistence of autonomous, specific, and ideal (platonic) morphological constraints. By equating genetic control with determining cause, it is postulated without further inquiry that there is nothing more to explain in what is being controlled. As Jacques Monod claimed, form is causally reducible to the primary structure of proteins; the remainder being dependent only upon thermodynamic processes.

As a historicist and dualistic conception, Neo-Darwinism rightly postulates the existence of a material principle of organization but negates any formal causality. It is at the same time a materialistic holism and a reductionism which posits the primacy of the functional, which reduces the structural connection and the positional organization of the parts to a mere spatial *contiguity,* and subordinates "internal finality" to "external finality" (to adaptation and selection). According to it, structure is reduced to heredity. It is historically *given* and its only necessity is that of its evolution. It is only an artifact of its own control, the expression of its genetic program.

Structural rationalism denounces in this conception the inconsistency of making history not only the cause of evolution but also that of the *stability* and *invariance* of species (cf. also Gould 1977a and Gould and Eldrege 1977b). It conceives organism not only as a complex genetically-controlled physico-chemical system, but also as a *structure,* that is to say as a totality organized by a system of internal relations satisfying formal laws and universals. The universe of organized beings is a *constrained* one which manifests a certain *necessity*. The structures are neither irreducibly diverse, nor the arbitrary results of evolution.

The fundamental hypothesis of structural rationalism is that the expression of the genotype by the phenotype remains incomprehensible until one introduces *positional information* controlling cellular differentiation. In organized beings there would be an *efficacy of position,* position selecting certain local metabolisms by triggering certain genes. And it is the understanding of such positional information, of such efficacy of position, that constitutes

the central theoretical problem of structuralism, not only in biology, but in all the other structural disciplines. For example, whether in Driesch's vitalism or in Waddington's theory of morphogenetic fields, the principal characteristics of organizational structures are:

(1) dynamical genesis, self-regulation and structural stability;

(2) equipotentiality, that is to say the fact that structures cannot be reduced to the interaction of components but include a reciprocal determination of *places,* of *positional values;*

(3) equifinality and homeorheses, that is to say the fact that development is itself structurally stable as process, its final state being in large part independent of its initial state;

(4) the drastic limitation of the set of elementary structures and the existence of constraints, of "laws of form;"

(5) the "generativity" of forms, the opening up of this limitation toward complexity.

These concepts are in fact truly regional categories for the region of morphological phenomena. They subsume fundamental properties of self-organization and ultimately refer back to this efficacy of position according to which a system of connections is a relational and dynamical network of positional values. Their categoriality which, as we shall see later, owes more to *linguistics* than to physics, determines the type of theory that is able to render the morphological and dynamical concept of structure intelligible. The main problem is to (transcendentally) deduce their *objective value,* enabling them to go beyond their reflecting status and thus permitting dynamical structuralism to go beyond the non-scientific stage of speculative vitalism.

3.3. Gestalt Theory and Phenomenology

In the domain of psychology, structuralism is exemplified by Gestalt theory where the same themes, the same problems, the same criticisms of reductionism and the same regional categoriality as those which have just been briefly sketched concerning biological morphogenesis can be identified. In his classical introduction Guillaume (1979) underlines that Gestalt theory is a rational monism which puts forth the category of structure at the same time in the physical, biological, and psychological regions. In psychology it proceeds first

with a critique of the atomism of sensations and associationism and maintains close links with Husserlian phenomenology. The concept of pure sensation is only an experimental artifact, a hypothetical explanatory concept, insofar as a sensation cannot exist outside of perceptual *organization*. Granted, there do exist peripheral excitations (for example, retinal) produced by external stimuli. But these are only controls of global percepts which integrate them cortically and are not their determining cause. The fundamental hypothesis of Gestalt theory is that it is impossible to treat a perception as an abstract system of relations between atomic sensations, for such a system is the product of analysis and analysis is a *real transformation* of mental states. Neither terms nor relations have therefore an actual psychological existence, and this is why perceptions must be conceived of as "complexes" (to take up a term borrowed from Meinong), as *Gestalten,* as *"organic unities which individuate and limit themselves* in the spatial and temporal field of perception or of representation" (Guillaume 1979). These organized and internally articulated structures are the result of an original formative activity. What distinguishes them from abstract systems of components in interaction is again the existence of connections determining positional values. They are non-summable totalities whose "moments" do not possess the status of independent parts detachable from the whole (cf. Merleau-Ponty 1948).

Rather than seeking for a phenomenological description of structures, the Gestaltists tried to theoretize them dynamically as natural phenomena. They put forth the hypothesis (brilliantly confirmed since then, cf. below) that "the principles of dynamics, because of their generality, extend beyond their purely physical applications" (Merleau-Ponty 1948: 56). As Guillaume remarks: "the explanatory value of the Gestalt depends upon the systematization which it will succeed to establish between the various forms, upon the construction of a sort of Dynamics which will make the laws of their transformation appear" (1979: 251-252). In other words, Gestalt theory conceives of organized beings, whether physical, biological, or psychological, "as subject to very general dynamical laws, those of organized wholes, which are neither specifically physical, nor specifically psychological, but common to physics and psychology" (Guillaume 1979: 253). Concerning these, Köhler speaks of *Eigenstruktur* governed by a principle of *functional proximity*.

Thus, at the level of natural phenomena (physical and biological), as well as at that of perception and of language mediating perception and world, before the structuralism of the 1950s and 1960s the category of structure was worked out in detail, at the beginning of the century, within the context of Austro-German philosophical rationalism, where the following bodies of ideas were closely interlinked:

(1) the conceptions of the founders of structural psychology, Stumpf, Meinong, and Ehrenfels (all students of Brentano, Carl Stumpf being himself the teacher of Husserl and of the Gestalt theoreticians of the Berlin School: Wertheimer, Köhler, and Koffka);

(2) Husserlian phenomenology (that of *Logical Investigations*);

(3) Hilbertian axiomatics;

(4) Wittgenstein and the Vienna School's reflections on language;

(5) through Jakobson, the *Prague Circle's reflections.

Following the intellectual collapse of Germany during the Nazi period, the *rational unity* of this context was irreversibly disjointed. There now remain only mathematical structuralism, logico-combinatory structuralism in linguistics and anthropology, and its misrepresentation by analytic philosophy of language and logical empiricism. In particular, the foundations of modern structuralism, rooted in biology, phenomenology and Gestalt theory, have been completely clouded over. It is therefore necessary to say a few words about them. (I shall here follow the important work on this point carried out by Kevin Mulligan, Barry Smith, and their colleagues; cf. Smith 1982.)

All of the classical debates about the relations of parts in wholes, from their Aristotelian origin up to the empiricists and passing through the Scholastic, were taken up again in a new vein from Brentano onward. A good many of these problems can be considered conceptually—but not necessarily scientifically—solved (for example, the physical content of the relations of causality and of interaction, the set theoretical notions of an element belonging to a set or of inclusion of a class in another, the nature of spatial connections in a space, the relations of syntactic dependency in a logical formula, etc.). But others, considered crucial by phenomenologists and Gestalt theoreticians, are still very open. Let us mention a few of them:

(1) That of the *objective correlate* of the classificatory relation between genus and species, whether in biology or in other domains (i.e., that of the objective value of classifications, or, in other words, of a *realistic,* ontological conception of abstraction).

(2) That of the *objective correlate* of *relational* accidents, whether static (such as contractual or kinship relations), or dynamic (such as *actantial* relations). This central problem (which will be discussed below) is that of

the states of affairs, which, without being objective in the strict sense of the term, are nonetheless the *objective correlates of their linguistic description.*

(3) That, as we saw, of the general problem of organization, whether of biological organisms or of perceptual Gestalten.

(4) That of what Husserl called the *non-separable* parts of a whole, or again that of the dependent "moments." For example, in the perception of an object, a perceptible quality such as a color is non-separable, except by abstraction, from spatial extension. In the same way the *apparent contour* of a form is non-separable. It cannot exist in an independent manner.

This last problem, that of dependency relations (also called relations of *foundation)* between a moment and the whole of which it is a non-separable moment, was investigated in detail not only by Stumpf and Meinong but also by Husserl (see Smith 1982). It can be looked at in two ways: either as a psychological problem, which opens up onto the field of Gestalt theory, or as a general ontological one. This last one is the route chosen by Husserl when he conceived of the concept of dependency as a *formal* concept and attempted to work out an "axiomatized" *formal ontology* of it. It is extremely ambitious, since it presupposed (a) the realist hypothesis that the relations of foundation (also called "metaphysical connections" by Husserl) are not simply psycholinguistic (i.e., valid only for mental contents and their expression), but *a priori valid for every realm of objects* and (b) that they therefore possess an *objective* content (within the framework of what later on would become for Husserl the *noesis-noema* correlation). Its importance should not be underestimated since (1) it played a basic role in Gestalt theory; (2) applied to *syntactic* units, to what Ehrenfels and Meinong called objects or complexes of superior order, it decisively influenced the Polish school of logic (in particular: Leśniewski and *Ajdukiewicz) and, through this school, everything done since in the realm of "purely logical" and "categorial" grammars; and (3) it is at the origin of Jakobsonian phonology, *distinctive features typically being dependent moments: phonemes are neither equivalent classes of allophones nor descriptive artifacts, but formal units constituted by relations of foundation, relations that are *real* in the sense of an *ontological autonomy* of the phonological level (cf. below).

*3.4. The State of Affairs (*Sachverhalte*)*

Before bringing up issues related to structuralism in semiolinguistics, it is necessary to sketch a crucial notion (which has generally been misinterpreted) linking linguistic structuralism to Gestalt theory, and originating in the realist conception of dependency relations. We mean the famous notion of "state of affairs" *(état de choses, Sachverbalt)*. In order to understand, beyond denotation, the descriptive relation between language and external reality, one must postulate a *third term*. If one considers a proposition describing an external fact (for example, an actantial interaction), then it is necessary to suppose that its syntactico-semantic structure reflects an *objective correlate,* in other words that there is an *"objective" structuration* of the fact—a system of *real* structural connections—which is linguistically expressed. Now such an "objective" structuration is not of a *physical* nature. It does not exist materially. It subsists ideally. Yet, though it can be expressed linguistically, nor is it of a linguistic nature. It constitutes a third, *phenomenologically real* term between expression and reality, a medium called a "state of affairs."

Granted its nature of third term, the concept of state of affairs can be looked at from two opposite sides. The first way, and this has become the dominant point of view in the philosophy of language, by identifying it with the external fact whose occurrence guaranties the truth-value of the proposition. Whatever sophistication is brought to it (for example, by intensional logics to explain the opaque contexts and the *de dicto*/*de re* gaps, etc.), this denotative conception reduces the duality between syntax and semantics to the one developed by the logical theory of models.

The second way is by attempting to understand how, as an "objective" structure, as a *phenomenological invariant,* as a reality which is neither physical nor logico-linguistic, it can *emerge* from the external fact. This point of view, which is much more restrictive, enables one to *constrain* linguistic structures by these of reality. It has, therefore, no more to rely on innatistic hypotheses (for example, of a Chomskian nature) to explain language universals. This is the point of view adopted by Thom:

> "Can we not admit (…) that factors of phenomenological invariants, which create in the observer the sense of signification, come from *real* properties of objects of the external world, and manifest the objective presence of formal entities linked to these objects, and about which it could be said that they are the bearers of signification. (Thom 1980a: 170)"

Obviously, such a position is tenable only if—and this has never been the case until now for lack of theoretical tools—one can (1) attain a synthesis of phenomenological

appearance and objective reality; (2) mathematically define, from the point of view of the mathematics of physics, the "formal entities" which are the "factors of phenomenological invariance;" and (3) therefore objectively understand the qualitative structuration of reality in states of affairs. As will be shown below, the concept of catastrophe provides the first synthesis between phenomenology and physical objectivity. It permits us for the first time to justify (from a non-idealist perspective) Husserlian realism by saying, with Thom, that:

> "The proper gcometrico-topological analysis (…) enables us to associate with every spatio-temporal process certain invariants of a combinatory nature [catastrophes] (…) that one can reasonably think play an essential role, by their fundamental character, in the verbal description of the process. According to us, this is the source of the original schematism which governs the linguistic organization of our vision of the world. (Thom 1980a: 24)"

> "The primary function of language [being] to transcribe in a form communicable by our organs the phenomenological catastrophes of the external world, (…) the message bearing an autonomous signification inherits the structure of the external catastrophe that it is supposed to signify. (Thom 1972: 329)"

In the absence of such a theoretical tool one is obliged to postulate, with Husserl or with Wittgenstein, that physics, even if it were perfect and complete, could not attain an adequate description of phenomenological states of affairs and that these are therefore apprehensible only through their linguistic expression. But then they become indistinguishable from it and consequently one is led to postulate that a proposition simulates—pictures—through its logico-linguistic structure a real (non-logico-linguistic) state of affairs, without however being able to say anything about the autonomous reality of the latter.

Since Wittgenstein's *Tractatus* this theoretical stumbling block is manifest in all contemporary linguistics and analytical philosophy which, as Ouellet (1982: 2) noted,

> "were constituted only by eliminating from their object and their method any phenomenological and ontological preoccupation which could have founded the concept of representation otherwise than on its accepted history,"

and where

> "the relation of language to the world—a relation which is language—is not explained but simply relayed by the relation of a metalanguage, conceived as a set of formulae (…), to a language perceived as a formal system. (1982: 1)"

In the absence of a synthesis of phenomenology and physical objectivity one cannot overcome the following alternative:

> "Is it language which gives being its place, creating in the world those discontinuities which we call states of affairs (…) those states to which we refer in thinking and in speaking; or is it rather these states of affairs which, perfectly constituted as phenomena in the being, lend themselves to discourse, to which they give their place in thought and in language? (Ouellet 1982: 10)"

In the *Tractatus,* the nature of the *logical image* (the proposition as "picture") is dual. On the one hand, it concerns the structural unity of the proposition, and, on the other, it establishes a homology between that structure and the structure of the correlative state of affairs, more precisely between the *syntactico-semantic* connections of the proposition and the connections of the state of affairs. From this point of view, the logical image *(Form der Abbildung)* is, in its form, the very form of the *manifestation* of the state of affairs *(Form der Darstellung)*. This is why the logical form *(logische Form)* becomes identified with the form of reality *(Form der Wirklichkeit)* (Ouellet 1982: 47-48). For Wittgenstein, it is this relationship of *pictorial* similarity that enables us to identify the meaning of the proposition with the evaluative conditions of its truth-value.

> "The possibility for an object to occur in a state of affairs (its logical form) and that of a proposition to have a truth value (its form of representation) are included in the possibility that a logical image has of being structured in its own way in accordance with the reality it represents (that is to say in its form of reproduction). (Ouellet 1982: 52)"

In other words, contrary to what happens in the logical theory of models, the comprehension of the relations between language and world presupposes the elucidation of the ways in which the qualitative structure of a state of affairs can emerge from objective reality. For, if this were not the case, what meaning could the supposed homology between a proposition and a correlative state of affairs have? For Wittgenstein, the qualitative structuration of reality into states of affairs corresponds to the way we think it. By thinking reality according to such and such a state of affairs, we apply to it the correlative proposition, this projection constituting the form of meaning *(Form der Sinn)*. In other words, for Wittgenstein, there exists an equivalence between the way in which a state of affairs (conceived as a system of real connections) manifests itself, and the way in which the

meaning of the proposition which supplies the logical image is thought. But, unless one wants to return to a traditional logic of representation, then, within this equivalence, it is necessary to go from manifestation to meaning and not from meaning to manifestation. It is necessary to make explicit objective "formal entities" by means of which the "factors of phenomenological invariance" exist, or, in other words, to root propositional meaning in the qualitative structuration (among other things perceptual) of reality.

3.5. Structuralism in Phonology

As far as the sciences of language are concerned, the structuralist conception can be traced back to Saussure and, in particular, to the elaboration of the fundamental concept of *paradigm* (in the sense of the opposition between the paradigmatic and the syntagmatic axes). The fundamental contribution of Saussurean structuralism is, as we know, to have substituted in the study of language *relational* criteria of identity to the classical substantial ones. The identity of a linguistic unit in a paradigmatic system is a *value,* that is to say, a purely *positional* identity. By using a "geographical" analogy, a paradigm can be viewed as a *categorized* domain *D*, as a domain which is decomposed into sub-domains D_i by a system *K* of boundaries. Each sub-domain D_i is defined by its *extension,* in other words by the categorization *K*. It is in this sense that the structure does exist: the *global* organization *K* determines, by being *implicitly* present in each of them, the *local* units D_i. A paradigm is therefore not a system of relations between terms defined beforehand.

As for their *value,* the terms of a paradigm (which can obviously possess in addition a substantial identity) do not have an autonomous existence. They can be defined only through their *reciprocal determination*. As specific interpretation of the third Kantian category of relation, the category of reciprocal determination is the fundamental category of structuralism. (Obviously one should not mistake category here in the philosophical sense for category in the sense of a sub-domain of a categorized domain; in the same way paradigm in the Saussurean sense should not be mistaken for paradigm in the Kuhnian sense.) It gives meaning to the famous structural "axiom" according to which difference ontologically precedes identity. Saussure is very explicit on this point (Ducrot 1968). According to him, there are no intrinsic boundaries which delimit the phonic and semantic zones covered by the signifiers and the signified of language. Each term of a paradigm tends to "invade" the whole paradigm, its domain (its value) being limited only through its conflict with the other ones.

The determination of a positional value is therefore a purely "negative" one through a process of limitation, limitation constituting here a specific interpretation of the third Kantian category of quality. Since they are subsumable under the categories of reciprocal determination and of limitation, the relations between the terms of a paradigm are structural connections, relations of dependency or of foundation in the sense used above. It is in this very sense that, for Saussure and for semiolinguistics in general, language is a form and not a substance (Coquet 1982).

The concept of paradigm was worked out by Jakobson in a phenomenological perspective as the founding concept of phonology. Whereas allophones are substantial units of an audio-acoustic nature and content (units of the substance of expression in Hjelmslev's terminology), on the contrary phonemes are abstract, distinctive and discriminatory units, of a functional and linguistic nature and content (cf. the classic *Preliminaries to Speech Analysis* by Jakobson, Fant, and Halle (1952); also Jakobson and Waugh 1979 and Malmberg 1974), describable as bundles of distinctive features and subject to formal laws. The theoretical problem is therefore to understand the link between phonetics and phonology, between the organization of the substance of expression and the articulation of the form of expression. How phonological categorizations and stratifications, whose description is the very object of phonology, can emerge as structures from the phonetic substratum, from the audio-acoustic flux?

For a long time this problem has acted as a sort of *antinomy* within the area of phonetics. It has led to a conflict between, on the one hand, the "substance-based" reductionist conceptions, which reduced phonological descriptions to epiphenomenal artifacts without objective value, and, on the other hand, the "form-based" structuralist ones, which asserted the *ontological* autonomy of the form of expression. For these the phoneme is

> "a unique differentiating unit without concrete qualities, but manifested, in speech, by an allophone having physical qualities (physiological, acoustic, perceptual) which translate their differential qualities in the world of physical realities. (Malmberg 1974: 220)"

In other words, the form of expression is an *abstract* system, comparable to the Aristotelian *morphe,* which is realized in the substance of expression, in the concrete process of speech. If one admits that it governs phonetic perception, then one is forced to proceed from the abstract to the concrete:

> "description proceeds…from the abstract and the functional to the concrete and material, from form to substance. (Malmberg 1974: 30)"

But the substance of expression is not a sort of undifferentiated style which would be informed by an ideal form, an essence, an eidos, foreign to it. It is highly *organized*. To avoid the speculative pitfall of idealistic holism, and in order to become an authentic structural doctrine (epigenetic and relational), phonological structuralism must therefore make clear how the articulation of a *discrete* form can emerge from the organization of a continuous substance. But this leads to a highly complex problem. As Ladefoged noted:

> "one of the major difficulties in achieving this kind of description is in relating the essentially continuous nature of speech with the essentially discontinuous nature of linguistic description. (1972: 276)"

And Didier Pisoni adds:

> "[The] lack of correspondence between attributes of the acoustic signal and units of linguistic analysis has been, and still currently is, one of the most important and controversial issues in speech perception. (1979: 334; cf. Massaro 1972)"

The key to solving this difficulty can be found in the very structure of phonetic *perception*. As Derwing noted:

> "Linguistic "structure" (…), if this term refers to anything real at all, must refer to representations or interpretations imposed upon the speech signal by language users, normally as part and parcel of the communication event itself. In short, psychological reality is not merely a convenient luxury which linguistic theory may or may not choose to be concerned with, but is rather the *sine qua non* for any linguistic construct which aspires to anything more than an epiphenomenal or artifactual status, and hence for any linguistic theory which can justifiably claim to go beyond the bounds of an arbitrary taxonomic system. (1972: 86)"

As we shall see, the fundamental character of phonetic perception is to be *categorical*. The important works on the morphology of phonetic sounds (the analysis of sonograms) developed since the early 1940s, particularly by the Haskins Laboratories (in particular Pierre Delattre, Alvin Liberman, Franklin Cooper, Michael Studdert-Kennedy, and Kenneth Stevens) have shown that these sounds depend on a small number of parameters called acoustic cues. Modern methods of acoustic synthesis enable the continuous variation of the

cues. If subjects are subjected to tests analyzing their perception of such continua, for example of a continuum *W* going, by continuous variation of the voicing cue (VOT: voice onset time), from the syllable [ba] to the syllable [pa], one notices two things:

(1) As far as the identification of the stimuli is concerned, there is, as could be expected, the formation of an interface *K*, of a threshold, of a boundary, of a frontier, of a catastrophe set, categorizing *W* into two domains which respectively correspond to [ba] and to [pa].

(2) As far as the discrimination of two adjacent stimuli is concerned, there is no intracategorical discrimination: subjects discriminate two neighboring stimuli only if they are situated on different sides of the interface *K*, in other words only if they are identified as being different. Discrimination is therefore subordinated to identification: "categorical perception refers to a mode by which stimuli are responded to, and can only be responded to, in absolute terms" (Studdert-Kennedy et al. 1970; cf. also Pisoni 1979). It is this latter characteristic which defines phonetic perception as categorical. Categorical perception is drastically different from continuous perception (such as in the case of colors), where discrimination is essentially independent of categorization.

Discovered in 1957 by Liberman, the deep phenomenon of categorical perception enables us to understand how perception can spontaneously render discrete the audio-acoustic flux, in other words how the discontinuous can emerge from the continuous. As Delattre showed in his famous article of 1968,"From acoustic cues to distinctive features" (cf. also Jakobson and Waugh 1979), as well as Liberman, Cooper, Schankweiler, and Studdert-Kennedy, in their equally well-known "Perception of the speech code" (1961), it permits us to link the audio-acoustic level of phonetics (the organization of the substance of expression) and the linguistic level of phonology (the abstract relational content of the form of expression): the phonemes encoded in the audio-acoustic flux being categorical, they have a psychological reality as discrete units.

Since the pioneering work done in the 1960s, the study of this phenomenon has greatly progressed. In particular, it was shown that it is for a large part *innate:* the learning of a specific phonological system consists essentially in deforming (and not in forming) an initial categorization K_0 through operations of displacement, erasing, and bifurcation of its thresholds (cf., e.g., Eimas 1980). But debate is still open concerning its explanation. In our

opinion, the most interesting and most plausible hypothesis was put forth by Stevens, in his 1972 article "The quantal nature of speech." Stevens considers percepts as Gestalten whose qualities are global spectral patterns of a superior order and are controlled by acoustic cues (whose content, according to Stevens, is articulatory) varying in a control space *W*. One then has only to suppose that phonetic perception is qualitative in order to understand its categorical character. Indeed, when control (acoustic cues) varies in a category delimited in *W* by the catastrophe set *K*, the percept is *stable* and remains *qualitatively invariant*. Perception being qualitative, no intracategorical discrimination can occur. On the contrary, in crossing *K*, one of the qualities of the percept becomes *unstable* and the qualitative type of the percept changes radically, and so does its identification. As Stevens notes,

> "there are certain articulatory conditions for which a small change in some parameter describing the articulation gives rise to an apparently large change in the acoustic characteristic of the output; there are other conditions for which substantial perturbations of certain aspects of the articulation produce negligible changes in the characteristics of the acoustic signal. (1972: 52)"

The import of this type of explanation is to make the phenomena of categorical perception perceptive cases of *critical phenomena,* analogous to *phase transitions* in thermodynamics. We can therefore apply to it (and to phonological categorization) the universal models of critical phenomena which are actually the catastrophe theory models (cf. Petitot 1982a, 1982b, 1983a, 1989b).

3.6. Actantial Structures and Case Grammars

In the syntactic domain, the structural approach goes back to the work of Tesnière (1959). For Tesnière, a sentence is first of all a system of connections which are, "incorporeal" (non-perceptible) and can be apprehended only by "mind." These oriented and hierarchized structural connections (relations of dependency in the sense used above), are not of logical essence and constitute an "organic and vital" principle of organization (this is the way Tesnière reformulated the Humboldtian *innere Sprachform).* With his so-called *stemmas,* Tesnière gave a graphic representation of them which is at the origin of the syntagmatic trees found since then at the basis of all formal descriptions of language.

> "The stemma clearly shows the hierarchy of connections. It schematizes the various nodes that link them into networks, and thus visually materializes the

> structure of the sentence. (…) The structural scheme of the sentence is none other than the visual representation of an abstract notion. (Tesnière 1959: sec. 3-9-3.10)"

For Tesnière, the structural connections define the *functions*; that is to say, the roles assigned to words "in the mechanism of expression and thought" (1959: see. 19.4). They are projected on the linear order of syntagmatic concatenations: "Structural syntax is based entirely on the relations that exist between structural order and linear order" (1959).

The modern development of generative-transformational grammars and of generative semantics could lead us to believe that the Tesnierian point of view has been adequately formalized, and therefore superseded. But this is far from being the case. Actually, these developments stem from a static, taxonomic, formalist, and logico-combinatory conception of syntactic structures and lead to a more or less sophisticated algebraization of them. From this point of view they are far removed from Tesnière dynamical, "vitalistic," Gestaltist perspective. Indeed, Tesnière always insisted on the fact (1) that syntactic structures are self-regulated organizations analogous to biological ones, (2) that structural syntax is neither a logical grammar nor a psychological semantics, (3) that it is functional and dynamical and not categorical (in the sense of grammatical categories) or static. His conception is an *actantial*— and therefore a "scenic"—one centered on the concept of *verbal valence*. "The verbal node…expresses a complete mini-drama. Indeed, like a drama, it obligatorily comprises a process, and generally actors and circumstances." (Tesnière 1959: see.48.1.)

After the development of the generative-transformational grammars one had to await the *case grammars* of Fillmore (1968, 1969, 1971, 1972b), Chafe, and Anderson (1971, 1975), and the *relational grammars* of Keenan (1972), Comrie, and Johnson (1974, 1977; cf. Cele and Sadock 1977) for this aspect to be again taken into consideration. Fillmore, for example, reverted to a scenic and actantial conception of syntactic structures. Based on a semantic interpretation of deep syntactic structures, classical case grammars, in spite of their success, encounter deep difficulties in the definition of case universals. Their fundamental hypothesis is that there exists a finite list of case universals (or functional categories such as Agent, Dative, Instrumental, Locative, Objective, Beneficiary) whose notional content is definable. These deep cases supposedly select semantic roles (actantial roles), which, although semantic, can be uncovered and justified by syntactic criteria (the thesis of the primacy and centrality of syntax). But as soon as different languages are compared, a conflict arises between, on the one hand, the *proliferation* of cases, brought about by their conception as sentence

discriminators, and, on the other hand, their *limitation,* brought about by their conception as universals. If we want to attribute a discriminatory notional content to deep cases, we must become involved with the lexical semanticism of verbs, and therefore cases begin to proliferate. If, on the contrary, we wish to attribute to them a general enough notional content for the list not only to be finite but also *limited,* then this content immediately becomes too general. As Willems has noted, the case roles "end up by losing all semantic value" (1978: 247). In short, the major difficulty, clearly formulated by Fillmore,

> "is the observation that nobody working within the various versions of grammars with 'cases' has come up with a *principled* way of defining cases, or *principled* procedures for determining how many cases there are, or for determining when you are faced with two cases that happen to have something in common as opposed to one case that has two variants. (1977: 70; our emphasis)"

A first solution to this difficulty has been proposed by Anderson (1971, 1975). Parallel with the analysis of phonemes into distinctive features, it consists of: (1) treating case contents as *complex* contents which can be decomposed into case features (multicase analysis of actantial roles); (2) identifying case features with a limited number of universals by taking up a fundamental hypothesis, the so-called *localistic* hypothesis, according to which the positional relations between spatiotemporal actants serve as scheme for the actantial relations in general (on the importance of the localistie hypothesis in structural syntax, cf. Petitot 1979a, 1979b, 1982a, 1982b); (3) positing that verbs select the case features; (4) elaborating a "generative grammar" of these selections.

Fillmore's solution is different. It consists in: (1) noting that several different semantic fields can serve as substratum to the same abstract scheme of actantial connections, and therefore, (2) distinguishing in case semanticism the part coming from the specific semantic field considered and the part—purely positional—defined by the "stemma." As Potts suggests:

> "wherever there are isomorphisms between sets of inter-relationships we should (…) recognize only one set of semantic roles. The differences between the roles in the two situations will be accounted for by the different semantic fields in which (…) the semantic field working upon the role to modify it. (1978: 454)"

Fillmore called these semantic fields "scenes".

> "Each scene is lexico-syntactically organized by a limited number of specific constructions which select relative cases "presenting precise syntactic and lexical characteristics. (Willems 1978: 247)"

Hence the slogan "meanings are relativized to scenes" (Fillmore 1977: 59).

In order to develop this scenic conception which, according to us, is truly structural, Fillmore resorts to the notion of case frame, the function of which is to mediate the descriptions of the situations and their underlying syntactic representations. The case frame assigns semantico-syntactic roles to the actants of the process expressed by the sentence, and this assignation constrains the choice of a *perspective* selecting, according to case hierarchy, one of the actants as the grammatical subject. In so doing, Fillmore maintains a conceptual definition of case. He puts it at the interface of thought and language and takes up the Wittgensteinian idea of a "pictorial" similarity between the syntactic structure of a sentence and the scene (the state of affairs) it describes:

> "such descriptions [are] in some sense intuitively relatable to the way people thought about experience *and* events that they [are] able to express in the sentences of their language. (Fillmore 1977: 62)"

This point of view shifts semantic analysis towards *cognitive* analysis. "The study of semantics is the study of the cognitive scenes that are created or activated by utterances" (Fillmore 1977: 73). We choose and understand linguistic expressions by "exciting" in our minds scenes, memorized prototypical situations relative to which expression has a descriptive and classificatory function. In other words, when set into perspective, an expression *evokes* the global ground from which it detaches itself. "It is as if descriptions of the meaning of elements must identify simultaneously 'figure' and 'ground'" (Fillmore 1977: 74).

Thus, in structural syntax, we find once more the same Gestaltist and phenomenological problems raised above. Language universals must be rooted in the perceptual and cognitive organization of the state of affairs. As Osgood noted:

> "It seems perfectly reasonable to think that much, if not all, that is universal in human language is attributable to underlying cognitive structures and processes. (…) Perceptual and linguistic signs and sequences must, at some level, share a common representational (semantic) system and a common set of organizational (syntactic) rules, cognitive in nature. (1971)"

According to A. R. *Luria (1975) “We must look for the roots of basic linguistic structures in the relations between the active subject and reality and not in the mind itself”.

The most delicate of these problems consists in achieving a *configurational definition* of case semanticism. Indeed, even if case contents are relativized to scenes, nevertheless it remains true that basic case semanticism is a purely positional one. Notional (actantial) contents of cases cannot be defined as autonomous contents, independent of one another. They can be defined only in terms of positions in schemes of actantial connections, positions determining and presupposing each other as values in a paradigm. The problem of structural syntax is a dual one:

(1) How can the schemes of actantial connections emerge, as self-regulated structures, as dynamical morphologies, as syntactic Gestalten, from the phenomenological organization of reality in states of affairs?

(2) How do these schemes permit the definition of case semanticism in terms of positional values?

To solve this problem it seems necessary to return to the localistic hypothesis and to posit that the possible structural connections between *spatiotemporal* actants have served as the matrix for the syntactic schemes in general. (For an historical presentation of the localistic hypothesis, see Hjelmslev 1935.) Such a hypothesis has been convincingly confirmed by Thom’s interpretation (1972, 1980a) of case universals in terms of elementary catastrophes. This interpretation makes possible the resolution of nearly all the theoretical difficulties raised here (cf. Petitot 1979a, 1979b, 1982a, 1982c, 1983). As Wolgqang Wildgen noted (1981, 1982), this constitutes a decisive step which brought into question many dogmas of generative-transformational grammars, of generative semantics, and even of case grammars.

The structure of the elementary interactions which are derived from paths in the bifurcation space of elementary catastrophes, defines different roles which can be roughly compared to the ‘schémas actantiels’ proposed by Tesnière and to the ‘case frames’ classified by Fillmore. The basic difference between the structures and the [catastrophe] semantic archetypes consists in:

(1) The *preverbal* character of archetypes. The structures proposed by Tesnière, Fillmore and others are only generalizations of linguistic structures found in natural languages.

(2) The foundations of the classification of archetypes in a formalism which is supposed to be basic for many biological systems. It is therefore universal in a very deep sense and it is of interdisciplinary relevance.

(3) The semantic archetypes are *irreducible gestalts*. They are not composed in a single combinatorial way. This fact constitutes a major difference in Thom's theory against all theories proposed up to now. Some of these have tried to describe field-like structures, but as no tool for consequently doing so was available they all drove away irresistibly attracted by the static-logical paradigm (Wildgen 1981: 264-65).

3.7. Semio-Narrative Structures

Actantial structures do not exist only at the sentence level. They do not have only a linguistic reality but also a *narrative* one. When narrative corpora are examined, for example myths, fairy tales, tragedies, novels, etc., it can be seen that at the (apparent) superficial level, these narratives relate plots between characters (actors) localized and spatiotemporally evolving, defined by thematic roles, linked by civil or contractual or emotional relations, and interacting together through conflicts, gifts, contracts, separations, unions, etc. Beyond this proliferation of superficial discursive structures, deep structures, called *semio-narrative* by Greimas, can be identified. The interest of this procedure (standard in semiolinguistics) is dual. It shows that: (1) abstract (non-figurative) discourses, whether philosophical, political, or scientific are also organized according to analogous structures, and (2) deep semio-narrative structures are actually experienced in passions, ideology, action, dreams, etc.

These two facts lead to the idea that, using an expression borrowed from Gilbert Durand, semio-narrative structures are *anthropological structures of the imaginary,* and that there exists a "grammar" for them.

One of the major interests of a semio-narrative grammar is to lay bare a relation between syntax and semantics which is very different from that ordinarily transferred from logical models to linguistics. We mean the projection (or conversion) of the paradigmatic axis onto the syntagmatic axis. Its understanding constitutes one of the central problems of structuralism.

The identification of a *syntactic* component in the deep semio-narrative grammar goes back to *Propp's work on the Russian folktale: *The Morphology of the Folk Tale*. Underlying the various plots of the characters, Propp isolated *functions* (typical actantial relations) *canonically* linked, expanding in a determined way as in a process of morphogenesis, and expressed in typical sequences: establishment of an initial lack (for example, the transgression of social norms, betrayal, etc.), contract between an Addresser and a hero,

succession of tests, first qualifying tests by which the hero acquires the modalities of wanting, knowing, and/or being able to (for example, the acquisition of a magical weapon through the intermediary of a helper), then the decisive test where the hero accomplishes a performance liquidating the initial lack (for example, killing a dragon), finally the glorifying test where the hero's performance is sanctioned by the Addresser. In other words, Propp identified and formulated invariant, stable and universal actantial structures. These are governed by an actantial syntax which *syntagmatizes,* along what Greimas has called a global narrative schema, an actantial *paradigm* constituted by the relations Addresser/Addressee, Subject/Object value, Subject/Anti-subject, Helper/Opponent (Greimas 1970; Greimas and Courtès 1979).

After Propp's work, credit for identifying a *semantic* component in the deep semio-narrative grammar must go to Lévi-Strauss' work on myth (1958; 1964-1971). Without doubt this is the most delicate and most difficult part of the structural analysis of narrative. Indeed, this deep semantic component is very different from the superficial, discursive and figurative semantics, which spreads the *lexical* semanticism in the superficial syntactic structures. If one remained at the simple discursive-figurative level of the deep actantial structures, then obviously one could still analyze narratives as myths. But one could not understand their *anthropological function*. It is precisely this function that Lévi-Strauss attempted to define. To do so he had to lay bare the *logical coherence* of myth and therefore to adopt a *semantic* and *non-morphologico-syntactic* approach. Hence his critique of Propp. By reverting to the classical conception of the paradigmatic-syntagmatic relation (according to which the paradigmatic dimension is reduced to a dimension of *substitution* which can be laid bare by means of *commutation* tests), Propp could uncover only syntagmatic invariants and, thus, was able to elaborate only an actantial syntax (cf. Coquet 1982).

Inspired by Jakobson's work in phonology, and borrowing the Hjelmslevian principle of parallelism between the plane of expression and the plane of content, Lévi-Strauss was thus led to introduce, in the theory of deep semio-narrative structures, the second fundamental aspect of the paradigmatic dimension, not substitution but *categorization* (cf. above). His famous and exemplary analysis of the Oedipus myth (1958: 236) is well known and, whatever the critiques made of it since, it had the great merit of showing that the syntagmatization of narrative was governed by semantic *homology:* the overevaluation of kinship relations (Cadmus seeks his sister Europa, carried off by Zeus; Oedipus marries his mother Jocasta; Antigone buries her brother Polynices in spite of the ban) is to their underevaluation (the Spartoi mutually exterminate each other; Oedipus kills his father Laius; Eteocles kills his

brother Polynices) what the denegation of autochthony (Cadmus kills the dragon; Oedipus slays the Sphinx; the dragon and the Sphinx being chtonian figures) is to its affirmation (affirmation manifested by the proper names, Labdacos [father of Laius] signifying "lame," Laius "askew," and Oedipus "swollen foot").

The fundamental idea is therefore that, underlying narratives, and particularly myths, there do exist deep semantic categorizations articulating values, constituting unconscious codes (kinship, natural, cosmological, economic, culinary, etc.), and projecting themselves syntagmatically. Although they can be designated within an adequate metalanguage, these deep values cannot be identified with the superficial semanticism. They operate in a contextual and global fashion. They select in the (highly overdetermined) superficial lexical figures specific semantic features (semes). But the contents they articulate (Life/Death, Nature/Culture, Man/Woman, Divine/Human, etc.) are not referentially definable significations. They are like psychic "forces" (drives and/or ideals) "giving meaning to life" and whose meaning is never grasped as such but only through conversion into actantial structures. More precisely:

(1) The deep semantic structures are imaginary universals.

(2) Unconscious, they exist only when axiologized and when ideologically invested in object values whose quest governs *actions* (narrative programs in Greimasian terminology) of the subject actants.

(3) Only the circulation of object values governed by actantial syntax enables their apprehension. In other words, they are not subjectivable as such but only through a logic of action.

(4) The function of actantial syntax is thus to convert into a narrative doing the fundamental semantics determining the deep anthropological meaning of the narrative. It is to solve, by simulating a "drama" staging them, the paradoxes of subjectivity.

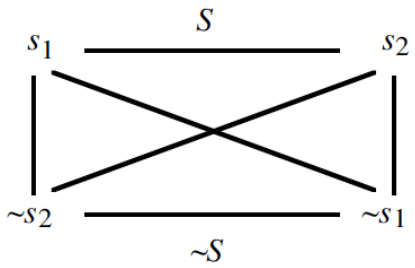
Thus the elaboration of a semio-narrative grammar must deal with three problems:

(1) What is an elementary narrative structure (we already know that it is an actantial one)?

(2) What is a semantic categorization (we already know that it is one analogous to those found in phonology)?

(3) What is the nature of the conversion of the fundamental semantics into syntax? What about the projection of the paradigmatic axis onto the syntagmatic axis?

These are (among others) the three questions Greimas' theory deals with. That is why in concluding this presentation of some aspects of structuralism, we would like to make a few remarks about it. In what concerns fundamental semantics, it is necessary first to define *formally* the morphologies of categorization constituting the *form* of the content (in Hjelmslev's sense). This is the aim of the celebrated semiotic square (for more detailed reflections on the semiotic square, see B.G.R.S. 1981, Nef 1976). Of a morphological nature, the semiotic square is a universal scheme of articulation ensuring, according to Greimas, the minimal conditions for grasping the meaning. "First nucleus of an elementary morphology," (Greimas 1970: 164), "first taxonomic instance" (p. 163), it operates at the "immanent level (…) where narrativity is situated and organized anterior to its manifestation" (p. 158). As such it is "susceptible of being transformed into a constitutional semiotic model" (p. 161) which is none other than "the elementary structure of signification utilized, as form, for the articulation of the semantic substance of a micro-universe" (p. 161). As a taxonomic form, as a scheme of articulation, as an elementary structure anterior to any semantic investment, it develops a semic binary category s_1/s_2 which correlates, in a relation of junction (conjunction/disjunction) and of reciprocal presupposition, two contrary semes, s_1 and s_2. This "development," this sort of morphogenesis of the opposition s_1/s_2 proceeds from the relations of contradiction $s_1/\sim s_1$, and $s_2/\sim s_2$ opposing the semes to their "negation" symbolizedby $\sim$). Hence the square: where S and $\sim S$ are respectively complex and neutral terms (in the sense given by Brøndal) associated with the category s_1/s_2.



Three types of relations (structural connections) constitute the square:

(1) *Hyponymic* hierarchical relations $s_1 \rightarrow S$, $s_2 \rightarrow S$, $\sim s_1 \rightarrow \sim S$, and $\sim s_2 \rightarrow S$ (as well as the inverse *hyperonymic* relations). These are relations of selection in Hjelmslev 's sense.

(2) Categorical relations of *contradiction* $s_1/\sim s_1$, $s_2/\sim s_2$ and of *contrariness* s_1/s_2, $\sim s_1/\sim s_2$

(3) *Hypotactic* relations of implication (of unilateral presupposition) $\sim s_2 \rightarrow s_1$ and $\sim s_1 \rightarrow s_2$, (as well as the inverse *hyperotactic* relations $s_1 \rightarrow \sim s_2$ and $s_2 \rightarrow \sim s_1$). These are also relations of selection.

These various relations can be classified into three "dimensions:"

(1) Two *axes*, the contraries s_1 — s_2 and the sub-contraries $\sim s_2$ — $\sim s_1$.

(2) Two *schemas*, the contradictories s_1 — $\sim s_1$ and s_2 — $\sim s_2$, the first being (conventionally) positive and the second negative.

(3) Two *deixes*, the implications s_1 — --$\sim s_2$ and s_2 — $\sim s_1$, the first being (conventionally) positive and the second negative.

Handled as a simple logical form and formalized in terms of elementary Boolean set logic, the semiotic square becomes trivial and of little interest. It simply reformulates "logical squares" going back to *Aristotle. But everything changes if one notices that it is, in fact, a *structure* in the strong sense of the term, that is to say, an "organic" and self-regulated system of relations of dependency and of foundation (in the sense used above) defining, as a phonological paradigm, *positional values*. The semiotic square is *not* of a logical nature. As Utaker (1974) has shown, the relations of contrariety and of contradiction are respectively *qualitative* oppositions and *privative* oppositions in the Jakobsonian sense. Therefore they must be treated as such.

Now the notions of opposition and presupposition refer to the primitive notion of *position* which is primitively topological and not logical. In the same way, the notions of conjunction and disjunction refer back to the primitive notion of junction, which is primitively topological and not logical. The formal essence of the semiotic square is therefore ultimately dependent upon a dynamic topology of places and connections and not upon a static logic of terms and relations. It is within such a non-trivial framework that we must formalize it and understand how a connection between two places (which, after the investment of the places by terms, becomes a qualitative opposition s_1/s_2) can develop morphologically -without any change in the number of places. It can be shown that this is possible by schematizing the semiotic square by means of elementary catastrophies (Petitot 1977, 1982a, 1983b).

Concerning narrative syntax, Greimasian theory conceives of the elementary actantial structures as the syntagmatization, by narrative programs, of the actantial paradigmatic relations. These can be reduced to the reciprocal presupposition between Addresser and Addressee (dimension of contract), between Subject and Object (dimension of the acquisition of modal competences and/or dimension of performance), and between the Subject and Anti-subject (dimension of performance). Concerning the basic relation Subject/Object, Greimas in particular conceives of the subject actant as an intentional subject (a subject of lack, a subject of the quest, a subject of desire) having as goal a *semantic value* (positively ideologized) invested in an object. That means that the basic narrative program is a program of *conjunction* between a subject and an object-value, quite similar to the conjunction between a predator and its prey.

This point of view raises a certain number of difficulties. For example, Ricoeur (1980) has emphasized that it is doubtful that the phenomenology of action, which if manifested narratively in all its richness, can be reduced to simple operations of conjunction and disjunction between subjects and object values. On the other hand, to conceive of semiotic subjects as intentional subjects obviously leads to the raising of questions about their intentionality. The joint problematics of belief (and of its avatars, seduction and manipulation) and of selection of object-values are linked to this problem (which would necessitate a reinterpretation of the connections between phenomenology and psychoanalysis) (cf. Petitot 1983a).

But the major difficulty remains the conversion of the fundamental semantics into actantial syntax, that is to say, the projection of the deep semantic categorizations onto the narrative programs. (For an analysis of certain aspects of conversion, see B.G.R.S. 1982.) In Greimasian generative theory, this difficulty is solved by the introduction of an intermediate level, called the syntax of operations, linked at the same time to the semiotic square and to the actantial structures. The main idea is that taxonomic relations constituting the semiotic square can be converted into logical operations on the terms they define. As Greimas remarks:

> "An examination of the conditions of the manifestation of meaning clearly shows that if signification, insofar as one attempts to find it in the object, appears as an articulation of fundamentally stable relations, it can at the same time be represented dynamically as soon as it is considered as a manifestation or as the production of meaning by the subject. Keeping in mind this dynamic aspect, a network of equivalences between the constitutive fundamental

> relations of the taxonomic model and the projection of these very relations, or operations, this time governing of these operations would be syntax. Thus, contradiction, as relation, at the taxonomic level establishes binary schemas; as operation of contradiction at the syntactic level it consists in negating one of the terms of the schema while at the same time positing its contradictory term. (1970: 165)"

If, therefore, an equivalence is posited between, on the fundamental semantic level, a seme *s* and, on the actantial level, the conjunction $S \cap O$ linking an intentional subject *S* to an object *O* invested with the semantic value *s*, then, through the mediation of the logical syntax of operations, the contradictory term $\sim s$ will correspond to the negation of this conjunction, that is to say to a *disjunction* $S \cup O$ programming *S* to "recapture" *O*.

As operational as it may be, this answer to the question of conversion is still incomplete and continues to raise problems. Indeed, it does not permit us to elucidate either the nature of the intentionality, or the mechanisms by which an unconscious psychic "force" can be invested in an object and so confer on it the "aura" of an object-value. But it must be said that these phenomena extend far beyond semiotics and that to understand them one must turn toward a "metapsychology" conceived in the Freudian sense or an anthropology of the imaginary conceived in the perspective of biological regulation. (Cf., e.g., Brandt 1982, 1983; Petitot 1982a, 1982b, 1983a; Thom 1981).

4. The Formalization of Structures

This overview of some aspects of structuralism shows that, as a conceptual system and as a methodology, as a regional ontology in the Husserlian sense, it is intrinsically trans-disciplinary (biology, anthropology, Gestalt theory, cognitive psychology, linguistics, semiology, etc.), and that in every domain where it can be said to be valid, it covers, as Piaget affirmed, "a common positive ideal of intelligibility" (1968). As a morphogenetic and relational doctrine of organization, it constitutes, next to physics, practically the only domain where the rational unity of very different phenomena has been achieved. The question of its *formalization* is therefore particularly crucial.

Now, concerning this most important question, one must recognize that structuralism, for lack of appropriate formal tools, has never been equal to its ambitions. Until the 1970s, it has

succeeded in developing only a *formalistic,* logico-combinatorial concept of structure. This is why, in conclusion, we shall attempt a critique of this and indicate an alternative.

Here, the formalistic point of view is itself dual and is concerned with either the formalization of structural *theories,* or the formalization of *structures* conceived of as natural phenomena (as objects of experience). The ideal of formalizing the theories goes back to Husserl's attempts "to axiomatize," in a quasi-Hilbertian mode, a formal ontology of general dependency relations ("theory" is used here in the sense of conceptual theory—developing the *a priori* constituents of a regional ontology—and not in the sense of mathematical theory.) It was taken up by Hjelmslev in the semiolinguistic domain and, for example, is the basis of Greimaslan epistemology. From this perspective, the theory can be considered as a *conceptual system* (a descriptive metalanguage) which, through a definitional hierarchy, enables one to derive the relevant concepts from basic ones. These basic concepts are thus *undefinable*. They have the status of *regional categories.* In Greimasian theory such are, for example, notions as continuous/discontinuous/discrete, relation, difference, opposition, junction, transformation, operation, etc. It is postulated that by giving them a *formal expression,* the descriptive metalanguage can be "axiomatized" and converted into a *formal language,* into a "pure algebra" (Greimas and Courtès 1979: 225).

The major difficulty encountered with this conception is that it can at best elucidate only the logical architecture of the theory and cannot, in any way whatsoever, lead to an adequate mathematization. In Kantian terms, it is based on a formal logic oriented towards the discursive form of knowledge and not on a transcendental logic oriented towards the objective content of knowledge. Here we meet with a philosophical and epistemological obstacle which cannot be underestimated but which is generally carefully shaded over (this shading is essentially due to the importance of logical positivism in the contemporary episteme.) It can be solved only if an explicit mathematical content can be substituted for the semantics of the regional categories. Taking up the Kantian term of schematism (i.e., of construction of a concept into a mathematically determined intuition), we shall say that no mathematization of a theory (whether structural or physical) is possible without a schematization of its categories: the schematization of categories is the key to every constitution of objectivity (in the Kantian, then Husserlian sense of "constitution").

We cannot help being struck by the fact that, in every domain we explored, the structural categoriality was always the same and that it had a content which, in the last analysis, was rooted in a *topological* intuition (position, junction, paradigmatic categorization, connection,

etc.). As we saw, every structure is, first and foremost, a structurally stable and (self)regulated system of connections between positional values. This crucial fact was deeply illustrated by Deleuze. Every structure is a "combinatory of formal elements which by themselves have neither form, nor signification, nor representation, nor content, nor given empirical reality, nor hypothetical functional model, nor intelligibility behind appearances" (Deleuze 1973: 303). Its elements "have neither extrinsic designation, nor intrinsic signification" (p. 304). They have "nothing but a meaning: a meaning which is necessarily and uniquely a 'positional' one" (p. 304). This is why the "scientific ambition of structuralism is not quantitative, but *topological* and *relational*" (p. 305). This is why "structuralism is inseparable from a new transcendental philosophy, where places are more important than what fills them" (p. 306). But then, the schematization of the structural categories depends entirely on the possibility of mathematically determining "the positional intuition" playing the role of a "pure form of intuition" for structural phenomena. It depends *hic et nunc* on the elaboration of a geometry of position,

Now, as Buffon had already noticed concerning embryology, such a geometry of position was in his time (and so it remained until recently) completely nonexistent:

> "Everything dealing directly with position is totally lacking as far as our mathematical sciences are concerned. This art which Leibniz called *Analysis situs* is not yet born and nonetheless this art, which would make us understand positional relations between things, would be just as useful and, perhaps, even more so for the natural sciences than art which has as its object only the magnitude of things; for often it is more necessary to know form than matter. (Buffon 1744: vol. 4, ch. 9; p.73)"

This means that structuralism essentially depends, as far as its mathematization is concerned, on the elaboration of a general mathematical theory of morphogenesis, and therefore on one of the most ancient and critical problems in the history of science. In the absence of such a theory, its concepts, although empirically valid, spontaneously drift toward a speculative vitalism which is scientifically unacceptable and can only be avoided by a formalism empty of content. This dialectical antinomy is the modern counterpart to the one developed by Kant concerning biological organization (cf. above). This has clearly been operating in modern structuralism. On the one hand, speculative perspectives, under the umbrella of materialism and/or psychoanalysis, have attempted to recover the obscure vitalistic power of Dialectic. On the other hand, formalistic perspectives were able to overcome their deficiencies only by

appealing to precarious and uncertain innate hypotheses. (Concerning this debate, which took place during the 1960s, cf., for example, Wilden's classical *System and Structure* (1972) and the dialogue between Chomsky and Piaget in Piatelli-Palmarini 1979.) It is only more recently, and in particular with the advent of catastrophe theory, that elements of a general mathematical theory of morphogenesis have been available to make possible the schematization of structural categories. This was a decisive breakthrough which for the most part renders the formalistic ideal obsolete.

The situation is quite different concerning the formalization of structures as a particular class of natural phenomena. Indeed, structural methodology had led to many relevant *models* through system theory and cybernetics, the development of *artificial intelligence, the various theories of-formal grammars, categorial grammars, intensional logic, etc. It should, however, be noted that all of this progress presupposes a *generalized reification* of structures.

In biology, for example, no matter how relevant cybernetics may be, one should not hide the fact that its use raises, as Thom noted:

> "very serious problems as soon as one attempts to pass from abstract schematicism to a material realization in space-time. (1980a: 154)"

From a formalistic perspective, one cannot understand how the structures represented by such formal schemas can emerge from physico-chemical properties. Such a perspective is valid "only for partial mechanisms, already put together, and in full functional activity…In no case it can apply to the global structure of living beings, to their epigenesis and to their physiological maturation" (Thom 1972: 207). This is why, in biology, it is pertinent to go back in a certain way to vitalism, but only after having transformed it into a dynamical geometry of position explaining the emergent structures "uniquely by means of local determinisms, theoretically reducible to physico-chemical mechanisms" (Thom 1983: 167).

> "Of the two points of view traditionally opposed in Biology, the vitalist one and the reductionist one, contrary to current opinion it is the latter that is metaphysical, for it postulates a reduction of vital facts to purely physico-chemical ones which has never been experimentally established. On the contrary, vitalism is based on the impressive array of facts of regulation and finality which cover the quasi totality of vital activity. (Thom 1983: 166)"

In the same way, in linguistics and in semiotics, the formalistic point of view comes up also against intrinsic limits. The current belief

> "that the strictly generative virtue of a structure, stemming from its very own form, must be admitted *a priori* and does not require any explanation"

needs to be questioned, as for natural languages

> "it is the self-limitation of the generative capacities of syntax which must be explained. (Thom 1980a: 164)"

To understand this self-limitation, one must introduce dynamics underlying the formal cinematics described by formal languages. One must base structures no longer

> "(on) the automatic iteration of certain operations, but on the contrary, on an intrinsic combinatorics given by dynamic interpretation. (Thom 1980s: 106)"

Conclusion

On February 2, 1706, Leibniz wrote to Reverend Des Bosses:

> "If one posits the plenitude of things (as do Cartesians) and the uniformity of matter and if one adds only movement one always obtains a succession of equivalent things;…and thus, no one can distinguish one state of affairs from another, not even an Angel; and therefore no variety could be found in phenomena: so, to figure magnitude and movement, forms must be added by which the difference of appearances arises in matter, forms that, it seems to me, can be sought intelligibly only by means of the Entelechies. (Leibniz 1702)"

From what has been sketched in this article, it ought to be clear that the mathematization of the concepts of entelechy and form constitutes the central difficulty of the structuralist episteme. Form is to structuralism what force is to physics, and therefore structural objectivity depends entirely on a general mathematics of forms. This theme appeared on several different levels:

(1) the level of biological organization;

(2) the level of qualitative structuration of the phenomenological states of affairs through which, as Leibniz said, "the difference of appearances arises in matter;"

(3) the level of the perceptive organization simulating the states of affairs;

(4) the level of the constraints imposed by this simulation on the cognitive, linguistic, and semiotic structures.

The systematic working out of these intimately linked questions is part of a major tradition which has constituted one of the main streams of philosophical thought without nevertheless having ever succeeded, for lack of tools, in reaching the scientificity of experimental method. There was here an epistemological obstacle the elimination of which structuralism has contributed to by introducing, in place of philosophical thought, new methods of objective determination. The question then arises of formalizing the structures according to the "things themselves." After having been formalistic, structuralism can, and must, be reborn as a new natural philosophy integrating organization and signification with purely physical explanations. Such are its actual epistemological value and ontological thrust.

In the introduction of his pioneering article, "Biologie et structuralisme" (1968), Thom asked the following question:

> "Can recent structural research in the human sciences, such as linguistics and anthropology, bring new methods for the enlightenment of an experimental science such as Biology? (1968)"

In other words, is it possible to attain a synthesis between dynamic structuralism, focusing on the problem of morphogenesis, and semiolinguistic structuralism, focusing on the form of signifying systems? It seems that a positive answer can now be given. For this, it is necessary first, as Thom proposes: (1) to reduce every structure (paradigmatic categorization, actantial interaction, morphogenetic differentiation, etc.) to a morphology; and (2) to reduce every morphology to a system of qualitative discontinuities on a substratum space (physico-chemical, semantic, or abstract). By distinguishing, on the one hand, the regularities, and, on the other, the variations relative to perturbations in the initial conditions, one can attempt to describe the empirically observed morphologies as aggregations and as concatenations of a finite number of structurally stable submorphologies, "morphogenetic fields," "chreods" (Propp's analyses are a good example of this). The next step is to elaborate local dynamical models to generate the chreods. Finally, one needs to elaborate global dynamical models which can, from a purely morphological point of view, account for the stable associations of chreods and therefore for notions of order and hierarchy.

Although vast, such a research program is no longer wishful thinking. Results have already been obtained which show that there exists a mathematically describable rational unity between phenomena of spontaneous organization of matter (dissipative structures),

critical phenomena (phase transitions, optical caustics, elastic buckling, etc.), biological morphogenesis and semiolinguistic structures. This possibility of a rationally founded and mathematically legitimated matching of, on the one hand, formalisms of fundamental physics, with on the other, the *ontological* concepts of structure, organization and event, conclusively confirms the intuitions of vitalists, phenomenologists, and Gestalt theoreticians. It leads to a rethinking of the rift, until now thought to be unbridgeable, between scientific explanation and hermeneutic comprehension. It uncovers an unexpected solidarity between the two main rational conceptions—physics and structuralism—of the modern episteme. This is an outstanding theoretical event and a decisive advance in what Michel Serres so acutely called "the North-West passage" separating the exact sciences from the human ones.

As was previously mentioned, this "passage" depends upon a new natural philosophy based on the (transcendental) constitution of a new regional ontology. For the main it invalidates the "structuralist" *ideological* rhetoric drift on the Unconscious, on the Subject's Negativity, on Materialism, etc. This drift was essentially due to the fact that structural rationalism remained cut off from its *real* ontology and lacked adequate mathematics, so that its authentic essence could only be expressed in a reifying formalism. In other words, a purely epistemological, methodological, and formalistic structuralism leads to the almost magical evocation of the transcendent problematic of the "originary place" (a noumenal one) producing structures (for example, the subject of the unconscious or the infrastructures). Unable to constitute its own objectivity, it subverts itself and drifts into a non-objective "ontology" since, as Eco has remarked, "an ontology of the originary place imposes, if all conclusions are correctly drawn, the destruction of the notion of structure" (1968: 363). But, thanks to the new natural philosophy animating catastrophe theory, this non-objective "ontology of absence"—which is none other than a new guise of materialistic and existentialist gnoseology already "deconstructed" by Merleau-Ponty in the *Aventures de la Dialectique*—can now be laid to rest without reducing structuralism to formalistic positivism.

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