

The Morphodynamical Turn of Cognitive Linguistics¹

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1. Introduction

In the 1970's and early 1980's a number of works were devoted to the use of morphodynamical models — that is, dynamical mathematical models of forms, patterns and structures — in structural and semio-linguistic disciplines. We dedicated three books and several papers to their applications in phonetics (analysis of the relationships between audio-acoustics and phonological categorization, models of categorical perception), actantial theory (case grammars, structural syntax)², and structural semiotics (semantic categorization, models of Greimas' narrative schemes and Lévi-Strauss' canonical formula of myth). These models came from natural sciences and participated in the increasingly radical *naturalization* of cognitive faculties (perception, action, language) undertaken by cognitive science. To emphasize this point, we qualified them to be part of a « Physics of Meaning » (see Petitot, 1992).

In parallel, during the 1980's the development of cognitive grammars led to a complete reversal of the theoretical status of the syntactic-semantic structures of natural languages. The convergence of profound theoretical transformations resulted in a spectacular progress of dynamical approaches — first with connectionist models of neural networks, then with dynamical models proper, the latter being a natural generalization of the former. In fact, as Daniel Amit (1989) has shown, introducing a hypothesis of full feedback and recurrence in a neural

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1. This paper is an extract of my recent book *Cognitive Morphodynamics* (Petitot, 2011).
 2. Throughout this paper, we use the terms « actant », « actantial », and « actantiality » to refer to semantic roles in the sense of case grammars and narrative grammars (see, e.g., Fillmore, 1977 and Greimas-Courtès, 1979).

network allowed to reinterpret the states of the network as the stabilization of its dynamics into one of several attractors during a « psychological » time (a few hundred *ms*). As Tim van Gelder (1994) states

If connectionism was the most dramatic theoretical revolution of the 1980's, it appears that dynamics is the connectionism of the 1990's.

In fact, we observe an irresistible movement of *naturalization* of eidetic and structural descriptions, not only in the philosophy of mind and in linguistics, but also, for example, in Husserlian phenomenology³.

The naturalization of eidetic descriptions has of course raised the question of their implementation in physical and biological substrata. During the 1980's, neuromimetic connectionist models have considerably advanced our understanding of fundamental cognitive phenomena such as categorization, learning or inductive inference. The use of sophisticated models coming from statistical physics has led specialists to formulate them in a mathematical universe where the dynamical point of view was dominant. This is why the connectionist implementation of cognitive structures and processes has converged with the dynamical point of view and, more precisely, with structuralist morphodynamical models.

We present here (rather rhapsodically) a few elements of this conceptual debate.

2. Morphodynamics in cognitive semiolinguistics

As mentioned above, during the 1980's the conceptual basis of semiolinguistic disciplines was deeply transformed. A new sensitivity emerged and the focus shifted to problems that had been left in the shadow so far. New foundations were asked for and new tools of conceptualization and formalization were transferred from other disciplines so far considered alien to semantic and syntactic problems.

2.1. *Characteristics of the cognitive turn*

The most striking characteristics of this mutation were the following :

2.1.1. *Critique of formalism* — The first characteristic was the desire to do away with the deficiencies of the formalist conceptions of natural language, which privileged mathematical tools adapted only to the analysis of formal languages (formal logic, formal semantics, intensional logic, categorical grammars, category theory and topoï, etc). In particular, the generativist point of view, i.e., the mechanistic conception of grammars as algorithms that generate languages from finite sets of rules, was the most strongly criticized (often unjustly and unfairly). Henceforth,

3. On the naturalization of phenomenology, see Petitot (1999a) as well as the whole volume *Naturalizing Phenomenology* (NP, 1999).

the naturality of natural languages was foregrounded, while the dogma of the centrality and autonomy of syntax was firmly questioned.

If we take the naturality of natural language seriously, the consequences that we can draw for the conception and modeling of linguistic structures are considerable. Indeed, we must then consider :

- (i) language as resulting from a phylogenetic evolutionary process concerning human cognitive abilities;
- (ii) the universals of language as universals of a cognitive nature correlated with the structures of perception and action;
- (iii) these cognitive structures themselves as processing an information that is present in the environment (semantic realism);
- (iv) linguistic structures as natural phenomena that are as transcendent to our consciousness as the physical, chemical or biological phenomena constituting our body : we « dwell » in our language as we dwell in our body, i.e., without being able to convert its intuition into a knowledge; our consciousness of our body bears only a false « naive » biology and no seed of any scientific biology; in the same way, our consciousness of language bears only a false « naive » linguistics and no seed of any naturalist scientific theory of language;
- (v) the formal automatism of competence as emerging from the natural underlying mechanisms of performance.

2.1.2. *Conceptual structures, embodiment and phenomenal world* — A second characteristic of the cognitive turn is the search for conceptual cognitive structures grounding natural language. The idea is that a conceptual structure underlying language can account for the compatibilities of language with perception and action. It is strongly supported by many works in cognitive science (see, e.g., Mandler 2004a, 2004b), which extensively show that there exists in infants a *preverbal conceptual thought* built from the perceptual categorization of objects, spatial relations, and events.

This leads to rejecting the classical thesis of the autonomy of syntax and insisting correlatively on the primacy of semantics, and the inseparability of meaning and grammar. As Ronald Langacker (1994) claims

A pivotal theoretical issue is the relation between meaning and grammar. (...) The central claim of cognitive grammar [is] that meaning and grammar are indissociable.

The rejection of the autonomy of syntax leads not only to privileging *semantic* structures but also grounding them in a theory of cognitive acts (a noetics in the sense of Husserl), on the one hand, and a *phenomenology* or ecology of the natural world (in the sense of Gibson), on the other hand. The latter concerns the qualitative structuring of the sensory world in things, qualities, states of affairs, processes, events, which are *morphologically* structured, both objectively (i.e., on physical bases) and perceptually (see, e.g., neo-ecological theories of perception such as

David Marr⁴). The idea is that both a cognitive psychology and a phenomenology of the natural world constrain universally the syntactic-semantic structures of natural languages. This strong phylogenetic hypothesis about language's naturality puts the deep structures of language very far away from the surface linguistic level. But its influence has nevertheless been growing in strength everywhere in linguistics.

The opening of the conceptual structure onto the phenomenal world is also an opening onto the body. Mind is « embodied » and semiolinguistic structures and universals are fundamentally constrained by the compatibility between language, perception and action. Hence the spectacular renewal of *phenomenological* problematics (those of the later Husserl and Merleau-Ponty).

2.1.3. *The organic connections with theories of perception* — Given their critique against formalism in linguistics, the cognitive theories employed in the new paradigm are evidently not those relevant to the classical cognitivist paradigm. In the classical paradigm, the external physical information transduced into neural information (via sensory receptors and modular peripheral systems) is processed by means of a formal symbolic computation operating at successive levels of mental representations that share the structure of *formal* languages, with their symbols, expressions, rules, and inferences.

The theories used in cognitive semio-linguistics are rather theories of perception, in particular those that admit the existence of *geometric-topological* and analogical mental representations (as in Shepard's and Kosslyn's works on mental images⁵) as well as those which treat cognitive acts in terms of dynamical models of performance (as in connectionism), and not in terms of formal descriptions of competence.

These new linguistic orientations are of course related to converging achievements in neighboring scientific domains. Major advances in image analysis, both in neurobiology of vision and computational models of image processing, have helped us better understand the multifarious representational levels of perception — from the lowest (early vision : retina and primary visual areas) to the highest (face recognition, etc.) cognitive levels. These discoveries made possible a whole set of new technical studies bearing upon the links between visual scenes and the syntactic-semantic structure of the statements describing these scenes. Similarly, new insights into the fundamental relations between perception and action have led to thorough works on the embodiment of these conceptual structures. The important consequences of an « embodied cognition » were especially well exemplified in robotics, e.g., with the work of Rodney Brooks at the MIT Lab of *Computer Science and Artificial Intelligence*.

From the cognitive viewpoint, semantic issues in natural languages underwent a significant reformulation. Semantics here is no longer a matter of « distinctive features », « generative semantics », or « selection rules ». The question becomes

4. See Marr (1982).

5. See Kosslyn (1980) and Shepard-Cooper (1982).

rather to explain how language can be *applied* to perceptual reality and actively structure it, as well as how this structuration is essential to further actions. Recent results let us imagine a near future in which robots will be able to trigger their motor behavior on the basis of the linguistic description of images acquired through their sensory devices, and communicate this description to other robots. Conducting this kind of research implies foraging into the deepest levels of motor and perceptual controls and their neural implementation. There lie many technical and difficult problems, whether neurobiological, algorithmic, computational, or mathematical, whose resolution is key to these cognitive approaches to semantics.

2.1.4. *Grammaticalization of Gestalts* — A fundamental non-formalist thesis proceeding from the non-autonomy of syntax is that *grammar specifies semantic contents*. This thesis is crucial for example for Ray Jackendoff, Leonard Talmy and Ronald Langacker⁶. One starts from the observation that lexicon and grammar can be differentiated by distinguishing *open* lexical classes (parts of speech : verbs, nouns, adjectives, etc.), whose cardinal is large and indeterminate, from *closed* grammatical classes, whose cardinal is small and fixed. This distinction is a revival of the traditional opposition between « categorematic » and « syncategorematic » elements).

The thesis (especially in Talmy) is that the closed classes grammatically specify certain very particular notions (e.g. geometrical features of objects and situations, point of view, focalization, thematization, figure-ground, force dynamics). These grammatically specified structures are *schematic* with respect to the states of affairs (the visual scenes) that they structure. They are idealized, abstract and topologically plastic.

2.1.5. *Iconicity and morphological structuration* — The importance of the connections between perception and language thus leads to the thesis that the latter is *anchored* into the former. Hence the problematic of *iconicity*. Iconicity of structures, particularly syntactic structures, does not mean that structures are concrete figures. It does not involve any « figurativity » in the classical sense but only an abstract iconicity of a schematic nature. Mental representations are construed as schemata, as generalized Gestalts, as a mental imagery that, as Kant had already explained in his theory of the *schematism* of empirical concepts, is a system of rules for the construction of referents. The image-schemata structuring mental representations are *types*, not tokens⁷.

This gestaltic⁸ conception of the structures of language became so influential in the 1990's that Herbert Simon himself, in a target paper *Bridging the Gap. Where Cognitive Science Meets Literary Criticism* of a special issue of the *Stanford*

6. See Jackendoff (1987), Talmy (2000a, 2000b), Langacker (1994).

7. For more philosophical details on iconicity, see Bordron (2011).

8. We take the liberty of using the adjectival form « gestaltic ».

Humanities Review (1994), defended the thesis that meanings are visualized as mental images and even claimed that

a mental picture formed by retrieving some information from memory or by visualizing the meaning of a spoken or written paragraph is stored in the same brain tissue and acted on by the same mental processes as the picture recorded by the eyes.

The schematic iconicity of mental structures is in fact a thesis about their *format*. It questions the *propositionalist* dogma (which is the cornerstone of all formalist conceptions), according to which mental contents must share a propositional format. The iconicity thesis is on the contrary that the format of mental contents is topological-dynamic. We could trace it back to Kant's schematism and Peirce's existential graphs. The idea is that the *spatio-temporal a priori* is deeper than the symbolic a priori : the human visual system is inherited from a very long natural evolution, while ideography and writing are extremely recent cultural acquisitions.

2.1.6. *Dynamical Structuralism* — Overcoming the formalist point of view also led to a change in the concept of structure. Structures can no longer be conceived as formal assemblages of symbolic elements connected by means of formal relations. They are now conceived as natural, organic, qualitatively self-organized and dynamically regulated wholes, as forms, Gestalts, or patterns. The perspective is now organizational, dynamical, and emergential : structures emerge from substrata, be they internal (neuronal) or external, while symbolic, discrete and sequential structures formally described by the classical paradigm are now equated with qualitative, structurally stable and invariant structures emerging from an underlying dynamics.

2.1.7. *Schematicity and categorization* — Schematicity grounds semiolinguistic structures in a basic cognitive activity, namely *categorization*. In cognitive grammars, even the most abstract syntactic structures are construed as data typing by means of prototypes (e.g., categorization of events).

These points of view have been well summarized by Peter Gärdenfors in *Conceptual Spaces. The Geometry of Thought* (2000) :

- (i) meaning is defined by conceptualization within cognitive models (and not by truth conditions in possible worlds) ;
- (ii) cognitive models are perceptually tailored : « a central hypothesis of cognitive semantics is that the way we store perceptions in our memories has the *same form* as the meanings of words » ;
- (iii) « semantic elements are based on *spatial* or *topological* objects (not symbols) » ;
- (iv) « cognitive models are primarily *image-schematic* (not propositional) » ;
- (v) semantics is primarily in relation to syntax, the latter is not a formal computation ;
- (vi) « concepts show *prototype* effects. »

2.2. *The path-breaking point of view of Morphodynamics*

On a number of essential points, the « cognitive turn » shows striking analogies with previous approaches and particularly with the « morphodynamical turn » operated by René Thom in the late 1960's.

Thom's and Zeeman's works were mainly concerned with models allowing the transition from neuronal dynamics to emerging cognitive structures, on the one hand, and from the dynamics of external substrata to emergent morphologies, on the other hand. In both cases, the basic problem is essentially the same : understanding how the interactions of a very large number of « micro » elementary units are able to generate « macro » morphological structures. This is the general problem of emergent structures in complex systems.

Let us briefly mention three key Thomian ideas that are still currently worked out :

- (i) The idea that a mental content can be identified with the topology of an attractor (i.e., a structurally stable asymptotic state) of an underlying neural dynamics, and that the syntactic trees of generative grammars are an abstraction of the bifurcations of such attractors into sub-attractors. This allows us to interpret the formal kinematics of linguistic competence and its logical-combinatorial structures as stable macroscopic regularities that emerge from the underlying microscopic dynamics. Hence a key analogy with physical models of *critical phenomena*, in particular with thermodynamical models of phase transitions (Thom, 1972; Petitot 1989g). This idea was taken further in connectionist models within the framework of the subsymbolic connectionist paradigm (see, e.g., Smolensky, 1988). According to this perspective, entities possessing a semantics are, on the « micro » subsymbolic level, global and complex patterns of activation of elementary local units mutually interconnected and computing in parallel. Their semantics is an emergent holistic property. The discrete and sequential symbolic structures of the « macro » symbolic level (symbols, expressions, rules, inferences, etc.) are qualitative, stable and invariant structures, emerging from the subsymbolic level through a cooperative process of aggregation. Here again, there is a key analogy with phase transitions. If we now introduce the Lyapunov functions of the attractors considered — what Paul Smolensky calls a « harmony » function (Smolensky 1986, 1988) — we are naturally brought back to Thom's morphodynamical models.
- (ii) The idea that there exist objective qualitative morphological macro-structures in the environment, which are of physical origin and emerge from the fine micro-physics of their substrata, and that it is therefore possible to develop mathematically a qualitative ontology of the phenomenal world (qualitative physics).
- (iii) Finally, the idea — basic for what is called the *localist hypothesis* in linguistics (see Petitot 1979, 1985, 1989b) — that topological and qualitative *spatio-*

temporal relations between the actants of a spatio-temporal scene are indistinguishably local and grammatical and, consequently, their *interactions* can be taken as general schemata for grammatical connections (in the sense of actantial relations). Hence, an iconic schematism of deep actantiality. This idea was echoed by cognitive linguists, cited above, and particularly by Ray Jackendoff.

There are however a few differences between Thom's and Zeeman's approaches and current cognitive connectionist models.

- (i) In contemporary connectionist models, the internal dynamics is explicitly specified while in Thomian models, it is only implicit. This difference changes nothing at the theoretical level since the bifurcation schemata of Lyapunov functions of attractors are in some sense universal (i.e., independent of the fine structure of the dynamics). But it changes a lot at the level of numerical simulations and at the experimental level.
- (ii) Thom construed phenomenology and ecology of the natural world in terms of a qualitative ontology, that is, in objective and emergent terms. Thus, for him, qualitative physics was a true mathematical physics. The problem was therefore to link it with cognition, in particular visual cognition, and understand how the retrieval of such qualitative morphological structures can be equivalent, on the part of the cognitive subject, to a certain type of information processing. In what is currently called qualitative physics, on the contrary, one usually thinks of qualitative and morphological structures in terms of Artificial Intelligence.
- (iii) Finally, as far as language is concerned, Thom related his morphodynamical approach directly to linguistic surface structures, which raised subtle issues. At that time, the mediation via conceptual structures – that is, precisely, the cognitive turn – was missing.

3. The problem of formalization and modeling

The developments of cognitive grammars bring to light the deep, difficult and fascinating problems of formalization. First of all, it must be observed that cognitive grammars are critically lacking formal models. This is a very striking and puzzling fact. Formalization should therefore provide them with more solid foundations and make them evolve from an intuitive and (richly) descriptive stage to a truly systematic and scientific stage. This lack of modeling can be explained by a certain suspicion against any « formalization » in the style that we have been accustomed to by theoretical linguistics and AI since the 1950's. Rejecting rule-based Chomskyan and AI-like theories, the tenets of cognitive linguistics were also led to reject formalization as a whole. As their opponents did, they implicitly took for granted that « formalization » equals « formal language » without considering that there existed *other types* of formal models involving other types

of working tools than symbols. Today, by contrast, numerous studies have shown that fundamental cognitive processes such as categorization, learning, inference, or even rule-extraction, can be explained in terms of dynamical systems, which bear no resemblance whatsoever to logical-combinatorial systems. This involves a complete shift in the conception of formalization. Given the difficulty and the epistemological intricacies of the problem, a closer examination is in order.

3.1. *The limits of formalism*

During the second half of the 20th century, the dominant conception of modeling in linguistics has been formalist, inspired by logic and computer science. This was due to two basic factors. First, the considerable achievements of formal logic and axiomatics have led a majority of philosophers, epistemologists, and linguists (but not mathematicians!) to think that mathematical theories could be reduced to formal languages in the framework of the syntax/semantics opposition in model-theoretic logic. The question of mathematizing linguistic structures has thus become an attempt to formalize natural languages in terms of formal languages. The developments, even more considerable, of computer sciences have definitely reinforced this point of view. As we have seen, the main consequence has been that only the automatism of competence, and their formal kinematics, have been formalized, and not at all the dynamical mechanisms of performance. Whether in the framework of such and such formal logic, or in theories of automata, generative grammars (Chomsky), categorical grammars (Montague), formal semantics, intensional logic (Hintikka-Kripke), or theories of categories and topoi, the same idea was gradually technically pursued and elaborated upon : linguistic representations are formal symbolic representations, upon which symbolic computation operates.

By definition, such formalisms « denaturalize » natural language. They equate competence with a system of rules and reduce the problem of concrete performance to mere problems of implementation.

It was not remarked very often that, in the standard transformational-generative conception of grammar, the reduction of syntax to a formal description of competence involves a fundamental constraint. As Chomsky claimed, transformations must be applied sequentially and must therefore be applied to objects of the *same formal type* as those they produce. Consequently, in the regression from surface structures to deep structures, one obtains abstract primitive structures (« atomic propositions » as in logic, « kernel sentences » as in Harris, etc.), which are of the *same formal type* as the surface structures (for instance syntactic trees). It is thus impossible to investigate their links with perception and action, on the one hand, and understand their emergence in terms of underlying dynamical mechanisms of performance, on the other hand. Now, the structures of perception and action, as well as the dynamical mechanisms of performance, undoubtedly impose certain *universal* constraints on grammatical structures. If we

do not take them into account, we are committed to interpreting these constraints as genetically innate.

That is why, as early as 1975, we have argued against this « obvious » classical symbolism, in which our ignorance of the physical foundations of mental structures forces us to reduce ourselves to an abstract characterization of competence. The conclusion of this « bad syllogism » is that the structural properties of language that cannot be derived from such an abstract characterization must be explained in innatist terms. It seemed to us, on the contrary (see Petitot, 1979), that the alternative « good syllogism » was the following :

- (i) we do not as yet know the physical neurophysiological bases of language;
- (ii) but we can nonetheless posit them and assume the existence of dynamical processes underlying performance, processes from which emerge the formal and abstract kinematic structures of competence;
- (iii) formal grammars formalize only certain aspects of these emerging formal structures;
- (iv) but there exists other aspects, linked with perception and action, which impose additional cognitive constraints on the « humanly accessible » grammars.

3.2. *Computationalism : the symbolic/physical dualism*

As far as cognition is concerned, the formalist point of view is inseparable from the classical symbolic cognitivist paradigm, according to which cognitive sciences are the sciences of mental representations expressed in an internal formal language that manipulates denoting symbols. It is postulated, as Daniel Andler (1987) has explained, that

the contact with the world allows the cognitive system to equip its internal symbols with meaning (p. 7).

In other words, it is assumed that

the structural properties of the world are expressible, by means of a sufficiently rich formal language, in the form of representations and rules (p. 8).

3.2.1. *The symbolic level* — The classical paradigm is computational, symbolic and functionalist.

- (i) First of all, it postulates the existence of neurophysiologically implemented mental representations, and differs on this point from purely eliminativist, reductionist, and physicalist conceptions which consider that mental representations are only artifacts of the psychological descriptions and do not possess as such any objective existence (see, e.g., Churchland, 1984).
- (ii) Then, it postulates that these representations are symbolic, i.e., pertain to an internal language of thought (Fodor's « mentalese ») possessing the structure of a formal language (symbols, well-formed expressions, inference-rules, etc.). On this point, it differs from conceptions that assume that experimental results

(for example, rotating mental images) argue in favor of non-propositional but geometric-topological mental representations (see, e.g., Kosslyn, 1980 and Shepard-Cooper, 1982).

- (iii) Finally, it postulates that, as in computer science, one can separate problems of hardware from problems of software and that symbolic mental representations are, as far as their formal structure and informational contents are concerned, independent of their implementation in physical substrata. It differs on this point from the emergentist conceptions which, on the contrary, consider that these formal structures must be conceived as stable structures emerging from underlying dynamical and statistical processes (see Thom, 1972, 1980; Zeeman, 1977; Rumelhart's and McClelland's PDP, 1986; Smolensky 1988; Petitot 1986, 1989c, 1989g).

Initially developed by Hilary Putnam and Jerry Fodor (but later rejected by Putnam himself), functionalism is the classical solution to the problem of relations between mental and brain states. It rests on the observation that a computational program, which is a set of logical instructions, can be implemented in computers possessing very different physical structures. In other words, it depends on the double analogy between, on the one hand, the logical steps of a program and mental states, and, on the other, between the physical states of a computer and brain states. Functionalists hold that the vocabulary meant to describe, explain and predict the states qualified as « brain states » are not ipso facto appropriate to describe, explain and predict states qualified as « mental states ». This non-reductionist position enables a rational division between neurosciences (the hardware part) and cognitive sciences (the software part). But it does not make room for an explanation of the qualitative character of mental states, which are defined less by their computational and inferential role than by their correlated phenomenal experience. Moreover, in the embryogenesis of biological cognitive machines like the brain, one cannot distinguish between software and hardware.

Thus for the symbolic paradigm, cognitive sciences must be founded on a computational theory of formal manipulations of symbolic representations. These representations process information, particularly information from the external world, and acquire in this way a semantic content. But the natural causality of the operations in which they are implicated is a strictly formal and syntactic one. In other words — and this is a problem — they are opaque with respect to their semanticity.

3.2.2. *The physical level* — Insofar as the informational input of mental processes is concerned, computational mentalism of the classical paradigm is inseparable from a standard physicalist objectivism. According to the latter, what is objective in the environment is reduced to what standard fundamental micro-physics (atoms, rays, sound-waves, etc.) teaches. Hence a *dualism* (strongly reminiscent of traditional philosophical dualisms) between the symbolic and the physical levels. In a seminal

book *Computation and Cognition* (1986), Zenon Pylyshyn gave an excellent exposition of this. Conceived in a physicalist manner, external information is a priori without relevant meaning for the cognitive system. It is converted into computationally relevant internal information by transducers (e.g., neurons' firing frequencies). There exists of course a nomologically describable causal correlation between external physical information and internal computational information produced by transduction, but this does not entail, however, the possibility of a nomological science of the meaningful relations that the subject holds with his environment. Indeed, on the one hand, the physically and causally described transduction is cognitively opaque. Its function is non-symbolic and is part of the functional architecture that constrains the structure of mental algorithms. On the other hand, linguistic « meaning » results from the operations executed by the symbolic representations, and these are not causally determined by the objective physical content of the external states of affairs. Hence, according to Pylyshyn, an irreducible gap between the internal cognitive representations and the external physical world. There is a universal physical language composed of physical terms. But there are not, *in this language*, any *physical* descriptions of what is relevant and meaningful in the environment for a cognitive subject. Quotations relating to this « strongest constraint » and this « extremely serious problem » could be listed together in Pylyshyn (1986, pp. 166–167)

the relevant aspects of the environment are generally not describable in physical terms,
 psychological regularities are attributable to *perceived*, not physically described properties,
 [there is a] general failure of perceptual psychology to adequately describe stimuli in physical terms.

Therefore, we must use *functional* perceptual and cognitive concepts lacking physical content. Physical lexicon and cognitive lexicon do not match. They are compatible only by way of transductions.

We shall observe that such assertions are acceptable only on the basis of certain hypotheses :

- (i) What exists as objective in the environment is reducible to what standard fundamental micro-physics describes; all the results of macro-qualitative physics are completely ignored.
- (ii) What is relevant must be first represented symbolically in order to be meaningful.
- (iii) Representations are equated with computation : the mind is computational.

3.2.3. *Difficulties of the classical symbolic paradigm* — As we have already noted, according to several specialists (Putnam, Searle, Dreyfus, etc.) at least two great problems remain unresolved in the classical paradigm.

- (i) On the side of the cognitive subject : the problem of meaning and intentionality. How can symbolic mental representations acquire a meaning, a denotation, an intentional orientation towards the external world? How can a cognitive system operate in accordance with the meaning of its symbols and symbolic expressions if it is causally related only to their syntactic form? It is not enough to say that meaning results from a subject-world « interaction », since this interaction is not nomologically describable and explainable.
- (ii) On the side of the external world : the problem of its qualitative and morphological manifestation. The phenomenal world is not a mere construction of the computational mind. Even if the phenomenal consciousness constitutive of the qualitative structuring of the phenomenal world into things, states of affairs, events, processes, etc., perceptually apprehensible and linguistically describable is only a tiny part of the computational mind (what Jackendoff calls the « Mind-Mind problem »), it must be supplemented with morphological and qualitative objective structures that emerge from the external physical substrata by means of a self-regulating dynamical process. Without such a supplement, phenomenality would remain incomprehensible. This properly « morphogenetic » level rests on the demonstrated existence of a morphodynamical level of reality that may well be called, as suggested by Per Aage Brandt, « pheno-physical ».

3.3. *Mathematization VS Formalization*

If we accept the emphasis on the « naturalness » of natural languages, we can state that, until now, the different types of formalization of linguistic structures have not at all modeled their naturalness. It is then necessary to rework formalization from the outset, without any sort of formalist prejudice, as a problem of mathematizing a specific natural kind of phenomena. It is not because mathematics is also a logical language that mathematical linguistics should be conceived as a game of more or less adequate translation between mathematical logic and natural languages.

Thus if we adopt an anti-logistic stance, we can conclude that *there exists a conflict between formalization and mathematization* in linguistic matters. Instead of having to develop the possibilities of translating natural syntaxes into formal ones, mathematical linguistics, on the contrary, must seek out the specific mathematical theories that are conform to the eidetic characteristics of the cognitive linguistic phenomena.

3.4. *Modeling and schematization*

In the formalist perspective inspired by Hilbertian axiomatics, one starts with primitive concepts of the descriptive-conceptual theory of a given empirical domain and applies the axiomatic method of « implicit definitions ». This method consists of substituting these primitive terms with syntactic rules that regulate and

normalize their use. The descriptive-conceptual theory is then translated into a formal language, whose logical syntax can be analyzed, its coherence tested and inferences controlled. This point of view construes the relation between pure mathematics and empirical reality as analogous to the relation between syntax and semantics in model-theoretic logic.

But in truly mathematized sciences like physics, the situation is completely different : primitive concepts are not axiomatized but *interpreted* by specific (possibly very sophisticated) mathematical structures. Of course, these structures themselves belong to axiomatized mathematical theories, but the mathematical axioms involved here have in general nothing to do with the primitive concepts of the descriptive-conceptual theory under consideration. To do homage to Kant, we have called this peculiarity a mathematical *schematization* of concepts.

By schematization, the content of fundamental theoretical concepts is converted into a universe of *specific* mathematical objects that can serve as models for the empirical phenomena at stake. Thus, theoretical concepts are converted into sources of mathematical models that can themselves achieve a *computational synthesis* of the phenomena. Thanks to an appropriate mathematical interpretation, concepts are translated into *algorithms* able to generate a wide diversity of *constructed* models, which can be compared to the empirically *given* phenomena.

3.5. *Morphodynamical models and connectionist models*

We have already seen that morphodynamical models generalize subsymbolic connectionist models. As Smolensky rightly insists

subsymbolic systems are dynamical systems with certain kinds of differential equations governing their dynamics (Smolensky, 1988).

There is a large number of phenomena well described by neuro-mimetic morphodynamical models.

- (i) The phenomena of categorization and (proto)typicality. The dynamics defines attractors, which can be assimilated to prototypes, as well as basins of attraction, which can be assimilated to categories. The models can be even further refined by viewing categorization as a process that results in a bifurcation of attractors. A good example is categorical perception in phonetics (see Petitot, 1989e).
- (ii) The complementarity between the syntagmatic and paradigmatic axes of language. If we teach (by means of supervised learning) a connectionist network the statistical syntactic regularities of a corpus of sentences and if we then observe how, in its hidden layers of internal states, it has organized the lexicon so as to be able to respond correctly, we observe that it has constructed *semantic paradigms*. This stunning result is due to Jeffrey Elman (1989). In fact, many linguistic problems (grammatical inference, anaphora, ambiguity, polysemy, etc.) can be treated in this manner (see, e.g., Fuchs-Victorri, 1994).

- (iii) The relationships between semantics of natural languages and perceptual scenes. For example, Terry Regier (1988) has constructed connectionist networks capable of learning the prepositional system of different languages and applying them correctly to static or dynamic configurations of objects.
- (iv) The phenomena of learning. Learning resolves an *inverse* problem. The direct problem is to deduce the dynamical behavior of the network (for example, its attractors in a categorization task), given the synaptic weights of a neural network. Learning consists, on the contrary, in modifying the weights in such a way that the network can carry out certain a priori fixed tasks.
- (v) Induction and generalization, i.e., the discovery of general rules from a finite series of examples. It is rather surprising to see a neural network learn rules. The step where inductive generalization happens has the status of a phase-transition.
- (vi) The material bases of the constituency of mental representations. This constituency, evident in the case of language, is very easy to describe and very difficult to explain. It raises a hard problem for mental representations implemented in a distributed manner on a large number of microscopic units. A hypothesis currently debated is that the fine temporal structure of interactions enables binding and constituency : when neural oscillators are *synchronized*, their common phase can act like a label for a constituent.
- (vii) The manner in which attention-focusing and pattern-recognition make the initially chaotic dynamics of the system bifurcate towards a simpler dynamics. It is this simplification of dynamics that would correspond to the recognition processes.

4. Morphological schemata and proto-linguistics

In our works we have presented in technical detail several morphodynamical schemata associated with the three main classes of entities represented in natural languages : objects, relations, processes, etc., focusing above all in each case on the perceptual basis. That is, the schemata that we presented — even if they must be conceived, according to what we have seen, as phenomenological and cognitive schemata universally constraining the semantics of language — should not in any event be considered linguistic models in the proper sense of the term. They are, we may say, only *proto*-linguistic schemata concerning deep structures and not surface structures.

It is essential to keep this point in mind. Indeed, our proposals pertain to a constellation of ideas where, as was strongly emphasized by Claude Vandeloise in his last works (see, e.g., 2006 and 2009), grammaticized structures rooted in perception (such as prepositions), perception being itself rooted in the qualitative structures of the world, are not only of a localist nature (be they topological,

geometrical, and/or dynamical), but also « functional » and « utilitarian », depending on the use of the items in particular contexts or circumstances.

In his beautiful tribute to Claude Vandeloise, Ron Langacker (2010) clarified with great acuteness « the relative weight of spatial and functional factors » in cognitive grammar. It is a general feature of *conceptual archetypes* (look e.g. at the semantic content of prepositions) to be highly polysemic.

Conceptual archetypes are experientially grounded concepts so frequent and fundamental in our everyday life that we tend to invoke them as anchors in constructing our mental world with all its richness and levels of abstraction. [...] Archetypes are basic conceptual units readily grasped in gestalt-like fashion. [...] Conceptual archetypes represent salient, essentially universal aspects of every day experience, as determined by the interplay of biological and environmental factors. Their emergence is a natural consequence of how we interact with the physical and social world, having evolved to cope with it successfully.

Even if conceptual archetypes are difficult to describe due to their evolutionary depth, they share a fundamental linguistic role : they are lexicalized, widely used metaphorically in their abstract sense, and constitute one of the main sources of grammaticizing.

A key to understanding grammar lies in the recognition that particular conceptual archetypes — especially salient due to their prevalence in moment-to-moment experience — provide the prototypical values of basic categories and canonical constructions.

So we can make with Bernard Victorri (2010) the hypothesis that, at the evolutionary level, *proto*-linguistic structures of a localist nature enriched by

dynamical, functional and intentional properties coming from our everyday life experience,

have been complexified not only by syntactic recursivity but also by

many grammatical specificities, such as the systems of modal or aspectual markers, or lexical properties such as polysemy.

5. Conclusion

In what we have called an « attractor syntax » (see Petitot, 1994c, 1995a, 2011), we have constructed *actantial graphs*, that is combinatorial structures which share the combinatorial properties and the systematicity requirements characteristic of symbolic structures. We have shown that it is possible to work out a dynamical conception of constituent-structures using morphological constructs that share the properties of a formal « syntacticity ». These morphological constructs do possess an internal structure. Moreover their generating physical mechanisms are « structure-sensitive ».

The fundamental difference between the classical symbolic paradigm and the morphodynamical paradigm is to be found in their conception of instantiation and implementation. To do syntax in a « gestaltic » way, we have to *generalize* bottom-up, data-driven and self-organizing perceptual algorithms of profiling (e.g., contour detection) and categorization. The crucial epistemological point is the following : mathematically, physical models are in general of a geometric-dynamical nature. Every physics is a geometrodynamics. Therefore, if we are able to extract syntactic structures by abstracting invariants from such a geometrodynamics we become able to understand the link between an ideal formal « syntacticity » and the underlying (neuro)physics. It is in that sense that geometry and dynamics are key to formal syntax.

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