Lecture Notes in Morphogenesis
Series Editor: Alessandro Sarti

Alessandro Sarti *Editor*

Morphology, Neurogeometry, Semiotics

A Festschrift in Honor of Jean Petitot 's 80th Birthday

Springer

Lecture Notes in Morphogenesis

Lecture Notes in Morphogenesis is an interdisciplinary book series which aims to face the questions of emergence, individuation and becoming of forms from several different points of view: those of pure and applied mathematics, of computational algorithms, of biology, of neurophysiology, of cognitive and social structures. The set of questions above concerns all the manifestations of Being, all the manifestations of Life. At the heart of contemporary embryogenesis lies an essential question: How can form emerge from the constant, chaotic flow? How can a sequence of purely informational elements — an a-signifying combination of chemical substances organized in the DNA molecule — evolve into the highly complex and structured forms of the living organism? A similar question can be asked when we deal with the morphogenesis of vision in neural systems and with the creation of evolving synthetic images, since digital technology makes possible the simulation of emergent processes both of living bodies and of visual forms. Finally the very idea that abstract structures of meaning could be captured in terms of morphodynamic evolution opens the door to new models of semiolinguistics, semiotic morphodynamics, and cognitive grammars. An entire heritage of ideas and concepts has to be reconsidered in order to face new and challenging problems: the theoretical framework opened by Goethe with the introduction of the word "Morphogenesis" is developed by D'Arcy Thompson in "On Growth and Form", it is reorganized with new theoretical insights by the classical structuralism of Levi-Strauss and formalized by the dynamical structuralism of René Thom. The introduction of the post-structuralists ideas of individuation (in Gilbert Simondon and Gilles Deleuze) and plasticity of structures builds a bridge to contemporary problems of morphogenesis at a physical, biological, social and transindividual level. The objective of this book series is to provide suitable theoretical and practical tools for describing evolutionary phenomena at the level of Free boundary problems in Mathematics, Embryogenesis, Image Evolution in Visual Perception, Visual Models of Morphogenesis, Neuromathematics, Autonomy and Self-Organization, Morphogenetic Emergence and Individuation, Theoretical Biology, Cognitive Morphodynamics, Cities Evolution, Semiotics, Subjectivation processes, Social movements as well as new frontiers of Aesthetics. To submit a proposal or request further information, please use the PDF Proposal Form or contact directly: *Dr. Thomas Ditzinger (thomas.ditzinger@springer.com)*

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Foreword

To Jean Petitot

It is a privilege to write a preface in hommage to Jean Petitot, but it is also a challenge. As this is a birthday celebration, I will address him directly as if we would be together for this happy birthday event.

Jean you are one of the, now rare, examples of a multidisciplinary thinker. You are an outstanding scientist who has also a remarkable expertise in philosophy and has devoted intense energy in training young minds. This book contains many descriptions of your achievements, and I will here only mention very few examples of my personal encounters with you and the reason for my deep respect and admiration. I remember your presence in the very first meeting on the possibility to create a new field called «Cognitive Sciences» and, since then, you have devoted an intense energy to promote a multidisciplinary understanding of brain function, including by accepting to lead the new Master degree that we had created with a group of colleagues covering a large sample of disciplines (DEA).

I also had the luck to participate in your early morning lessons in Ecole Polytechnique which aimed at an attempt to raise the interest of the future engineers to work on the brain. I remember the group of about twenty students coming, (half awake!) at 8 a.m. to listen to various lectures on our new domain. I admired the original method of initiation. You asked pairs of students to come and visit the speaker *before* the lecture in our neuroscience, psychology, etc., labs. They had to read papers on a topic relevant to the subject of the lecture and discuss them after the lecture. This pedagogic method is a typical trait of your very profound approach to any research subject and the real interest you have in the individual qualities and curiosity of young students to induce creativity. This was also a very clever way to try to bring to us some «polytechnicians» who enriched our recruitment and the scientific solidity of our work.

I also want also to say how important was your contribution to the «Phénoménologie and Cognition» group you co-organized in Paris. About twenty of its members produced, in 1999, the book you edited with Francisco Varela, Bernard

Pachoud, and Jean-Michel Roy on «Naturalizing phenomenology».[1] For a neurophysiologist trying to decipher the intrinsic brain and body operations underlying perception action, memory, decision, etc., your creative approach provided us with general concepts, and innovating thinking guidelines. They corresponded to the tradition of Husserl and classical phenomenology, but also stemmed from the more recent works of Maurice Merleau-Ponty for instance. The parallel efforts made in the USA for the creation of a «neuro-philosophy» and the debates between the promotors analytical philosophy and phenomenology generated also a very stimulating environment to allow us to design our experimental questions, in a more general theoretical frame. The present solid existence of a very multidisciplinary Cognitive Science as a domain, recognized worldwide, owes a lot to your pioneering efforts to combine bottom-up and top-down studies of brain function.

Several chapters in this book will mention your mathematical contributions to the understanding of brain mechanism of vision, and I will not comment on this major part of your science. I would like in this friendly preface to praise several of the qualities that I and I believe numerous persons have appreciated over the years. The most striking ones for whoever has had the chance to work or discuss with you are your modesty and patience. You are always ready to share to immense knowledge and culture but you hide them with this soft voice and reserved attitude which is the quality of those who are attentive to what others have to say. You also are generous with your ideas and your time and have always what our British and American friends call: «the quiet look of the guy who is trying to accomplish something».

You also have a deep devotion to what we have called with Carlo Ossola and Brian Stock: «La pluralité interprétative»[2] which is the basis of tolerance. This world is in turmoil and understanding the brain will require the type of cooperations between disciplines you encouraged This is crucial if we want to avoid the warning in our collective book recently published: «Sapiens: Métamorphose ou Extinction?»[3] and understand and prevent the continued capacity of man to engage into violence and hatred.[4]

[1] Jean Petitot et al. (Dir) «Naturalizing Phenomenology. Issues in Contemporary Phenomenology and Cognitive Science». Stanford University Press. 1999.

[2] Alain Berthoz, Carlo Ossola, Brian Stock (DIR.) (2010): «La pluralité interprétative». Online book. 24 June 2010. URL: http://conferences-cdf.revues.org/154.

[3] Le Floch'Soy Y., Berthoz A. Sanchez C (Eds.) (2022) «Sapiens: Métamorphose où extinction?» Humen Sciences. 485 pp.

[4] Itzhak Fried, Alain Berthoz, Gretty Mirdal, (Eds.) (2021) «The brains that pull the Trigger.» Odile Jacob. New York, 534 pp.

I wish you good luck in the future. Jean Petitot it has been for me a chance to meet you and that our paths crossed so many times, and a chance for our scientific community to have in you both a «savant» and a faithful friend.

Paris, France

Alain Berthoz
Pr Honoraire at the Collège de France,
Member French Academy of Sciences
and Academy of Technologies,
American Academy of Arts
and Sciences and Belgium Royal
Academies of Medicine and Sciences,
Bulgarian Academy of Medicine

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Chapter 1
Introduction

Alessandro Sarti

Abstract Jean Petitot is a polyhedric thinker whose contributions has been fundamental in a number of disciplines, such as epistemology, morphodynamics, differential geometry, structural semiotics, neurogeometry, phenomenology, linguistics, cognitive grammars, the theory of catastrophes, social sciences, literary studies and aesthetics. This book is a homage to his huge contribution about the main concepts of *morphogenesis* and *meaning*, that constitute the center of gravity around which Petitotian reflection revolves and returns. This chapter is just an introduction to the topic and to the brilliant contributions of authors who have accepted the invitation to take part to this tribute. An extended bibliography of Petitot works is included.

1.1 Jean Petitot: A Multiverse of Science and Humanities

First of all, let me express my gratitude as the Editor of this Festschrift to celebrate the 80th birthday of Jean Petitot. I'm just a very humble and undeserved reader of the work of this polyhedric French intellectual and I was lucky enough to work with him for several years. But, thinking about it, is probably true that there is even no ideal reader for his work. What reader would simultaneously master epistemology and transcendental philosophy, morphodynamics and differential geometry, structural semiotics, neurogeometry, phenomenology, linguistics and cognitive grammars, singularity theory and topology, social sciences, literary studies and aesthetics?

And yet there is a center of gravity around which Petitotian reflection revolves and returns, that is the formalization of the concepts of *morphogenesis* and of *meaning*. It is no coincidence that his work 'Morphogenesis of Meaning' [11, 15, 23], perhaps his most influential one, addresses exactly the issue to schematize the differential emergence of sense trough the theory of catastrophes of René Thom.

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It is the structural dynamics approach that traces the horizon of Petitot thinking, as a perspective allowing to overcome any logicist reductionism in favor of a morphological genesis of meaning, as he himself writes: "A 'structural space' is a space divided into domains (positions) by a system of differences; it is a space of coexistence, of co-location. [...] Using a geographical analogy, one could say that a paradigm is a region D categorized and broken down into sub-regions Di thanks to a system K of boundaries. Each sub-region Di is defined by its extension, i.e., by categorization K. It is in this sense that there is structure, as the global organization K, implicitly present, determines the local units Di" [11]. Then a catastrophe dramatizes a dynamic of conflict between categories, that are given by a partition of the space of possibility. These dynamics of conflicts are taken by Petitot as the core of the becoming of forms in embryogenesis, neuroscience, semiotics, anthropology, aesthetics and literary studies. That's the universal way of deploying a semiotic 'rise' of form to meaning.

The scientific path of Jean Petitot develops between these two poles, topology and meaning. At stake it was to challenge the hiatus separating the exact sciences from the humanities, that was the main point of the Petitot seminar of EHESS Epistemology of Models. It was the place in which to talk at the same time about Du sens (Greimas, 1970) and Stabilité structurelle et Morphogenèse (Thom, 1972).

By designing the appropriate qualitative dynamics between the two poles, form and meaning, it is possible to understand the Saussurian sign in structural semiotics, or the Greimasian semiotic square [8] for deep narrative structures [13] or even the canonical formula of the myth of Lévi-Strauss in structural anthropology [12, 19]. These are just few results in applying the theory of catastrophes to the emergence of meaning.

But it is biological morphogenesis the triggering occasion for the whole structural dynamics approach. Embryogenesis is considered by Thom/Petitot as a bifurcation process, as a sequence of elementary catastrophes, in such a way that an undifferentiated tissue differentiates in an endoderm and ectoderm that in turn bifurcates in a mesoderm and so on to arrive to build the metazoan early morphogenesis and subsequently the entire organogenesis [26]. The theoretic challenge is to integrate the local cellular metabolic mechanisms into a coherent picture of the overall dynamics of the organism. For Thom-Petitot, the organism is not only a genetically controlled physico-chemical system, but also a structure, that is to say a totality organized by a system of internal relations satisfying formal laws. His hypothesis is that the expression of the genotype by the phenotype remains incomprehensible until positional information controlling cell differentiation is introduced. Meaning that the positional distribution is selecting certain metabolic regimes by triggering some genes more than others. And it is the understanding of such positional information that constitutes the central theoretical problem. Both Thom and Petitot are interested in the equation of Turing's morphogenesis from a topological point of view. It is the bifurcation diagram of such dynamics that represents the deep structure of the phenomenon, the formal law underlying the sequence of successive differentiation leading to organogenesis [30, 31].

In my personal life I met the scientific path of Petitot due to his exceptional contribution in neuroscience, and particularly visual neuroscience. In fact, since the end of 90ies Jean outlined that neural dynamics have to be studied in very specific geometries, defined by the intrinsic connectivity between neurons in the visual cortex. In this way he introduced the concept of Neurogeometry and founded a completely new research line able to integrate mathematical modeling, cognitive neuroscience and phenomenology of perception [20, 43]. It is during my postdoc years at the Mathematics Department of U.C. Berkeley (1997–2000) that I became aware of this line of research. With Jean we started an exchange of letters about perceptual completion of Kanizsa images. I had just published my research with James Sethian about the completion of Subjective surfaces on the Kanizsa triangle [35–37] and Petitot had published his paper with Jannick Tondut on contact structures of the visual cortex [20, 43]. The Berkeleyan model was able to reconstruct the Kanizsa surface as a minimal manifold on the Riemannian metric induced by the image. The model of Jean was able to complete illusory boundaries with the right curvature. While the Berkeleyan model was just phenomenological, the Jean's model was both neurophysiological and phenomenological, able to take into account the results of Kanizsa as well as the structure of horizontal connectivity in the primary visual cortex. The intervention of Giovanna Citti, great specialist of sub-Riemannian geometric analysis has been crucial to understand the problem from a mathematical point of view and to develop it until the contemporary results. This has been the beginning of a scientific cooperation and friendship with both that would last 25 years [2, 32, 38, 39]. To follow this research line between neurogeometry, morphogenesis and meaning I joined in 2005 the CREA that was directed by Jean and subsequently the CAMS, i.e. the Mathematics Center of EHESS in Paris, that was the original laboratory of Petitot. I will be forever grateful to him for welcoming me at CREA and at CAMS and to have introduced me in the French scientific and cultural debate, trying to integrate human and natural science in the same cultural discourse.

Since then, the intellectual and academic activity of Petitot is not decreased with the years, almost the opposite. A number of important works have been published in recent years. Just to mention the several papers in neurogeometry until the volume "Elements of Neurogeometry: Functional Architectures of Vision", published in the Springer-Nature Series Lecture Notes in Morphogenesis [33]. Other two volumes on the same topic are ready to be published while I'm writing. His organization of seminars and meeting has been particularly important in the last years, as in case of the "Neuromathematics" seminar of EHESS and College de France, (co-organized by G. Citti, J. Petitot, J. Ribot, A. Sarti). His presence was fundamental also at the EHESS seminar "Post-structural dynamics", I founded in 2019 after the publication of [41, 42]. In all these situations Jean's intellectual contribution has been remarkably generous, of great breath and full of constructive criticism in all occasion of debates.

In the following I will recall very briefly the main lines of investigation of Jean Petitot in the topics of Neurogeometry, Semiotics and Epistemology just to contextualize the interventions of the specialists throughout the volume. And at this point let me thank all the brilliant authors who have accepted the invitation to take part to this tribute. Without their generosity the making of this gift would not have been

possible. A last point: Since as Editor of the volume I'm just collecting the work of others and my contribution is negligible, I allowed myself to make something I hope can be of some utility. So I collected an extended list of Jean's publications (limited to the subjects of the volume) that constitutes the last chapter of this short introduction. I hope that it can be useful both to orient the work of young researchers and to give a very immediate idea of the vastness, diversity and importance of the intellectual production of Jean Petitot.

1.2 Neurogeometry and Mathematics

For Jean Petitot dynamic models are an essential part of cognitive neuroscience. They make it possible to develop a physicalist point of view on cognitive sciences, that is essential to achieve his main goal: naturalization of human sciences. Regarding neuroscience, the study of the primary visual cortex from a geometric and dynamic point of view is then absolutely pivotal to understand visual perception and the constitution of morphological units. The main object of study of Petitot is then the geometry of functional architectures, that is the intrinsic geometry of neural connectivity. Petitot has shown that the functional architecture of simple cells in V1 implements a very precise geometric structure, that of the contact structure of fibrations having as its base the retinal plane and as its fiber the projective line of the directions of the plane. This contact structure can be implemented in the connectivity between cells leading to physico-mathematical models of neuronal activity which have been developed by numerous specialists such as Paul Bressloff and Jack Cowan [1], Yves Frégnac, Jan Koenderink, and Jean Lorenceau.

These models provide a very interesting hypothesis about the integration of contours starting from scattered local informations. Indeed, given a curve $y = f(x)$ in the retinal plane, it can be "lifted" in the fiber space V of the 1-jets of the curves by fiberizing the tangent $p = dy/dx$. The natural contact structure on V is defined by the field of planes tangent to V which are in the kernel of the 1-differential form $w = dy - pdx$ (which is nothing other than the condition $p = dy/dx$). The curves which "lift" in V the curves of the retinal plane are by construction tangent to these planes and are therefore the integral curves of the contact structure. Moreover, Petitot has shown in collaboration with Yannick Tondut [20, 43] that this structure corresponds to a mechanism proposed by Field, Hayes and Hess to account for psychophysical experiments on the integration of contours: the association field [3]. The horizontal connectivity of the visual cortex seem to implement this local pattern of association. An important application of association mechanisms concerns the explanation of subjective contours [6]. The idea is that they are solutions of a variational problem in the 1-jet bundle which associates low length and low curvature. A first class of curves, called elastica, seem relevant as outlined in by David Mumford in [7]. But it is possible also to consider curves which are "geodesic" in the contact structure of the bundle. They are horizontal curves of the tangent bundle. This is a problem of geodesics in a so-called "sub-Riemannian" geometry, where distances are only

defined on the contact planes. This perspective opened a new field of application of sub-Riemannian geometry that Petitot has developed in several papers with the author of this introduction together with Giovanna Citti [2, 32, 38, 39]. At least two volumes of Petitot that open the field and integrate many works of the neurogeometric community have to be mentioned: The volume published by l'Ecole Polytechnique in 2008 "Neurogéométrie de la vision. Modèles mathématiques et physiques des architectures fonctionnelles" [27] and the volume published by Springer-Nature "Elements of Neurogeometry. Functional Architectures of Vision", in the Series Lecture Notes in Morphogenesis [33]. As well as Petitot edited two special numbers of journals collecting specific papers on neurogeometry: the Special Issue of the Journal of Physiology-Paris in 2003 "Neurogeometry and Visual Perception", edited with J. Lorenceau. And the Special Issue of the Journal of Physiology-Paris in 2009 "Neuromathematics of vision", edited with Sarti and Citti [40].

Three contributions in this volume testify and continue this work of Petitot in neurogeometry authored respectively by Yves Frégnac, Jan Koenderink and Andrea van Doorn, Giovanna Citti and Alessandro Sarti.

The contribution of Yves Frégnac as neurophysiologist has a double value, since it recall very affectionately the history of his meeting with Jean Petitot, celebrating both the scientist and the friend, and at the same time he contextualizes the common line of research in the field of integrative neuroscience and its development during the years. The progress of geometrical modeling in brain sciences is at the center of this paper.

Jan Koenderink and Andrea van Doorn provide an original combination of formal, ontological and phenomenological aspects of visual perception ranging from geometric optics to phenomenology of visual awareness. They observe that vision presents many, mutually disparate ontological strata that they call as the physical, the sentient, the sapient, the mystic and the Platonic: "The physical stratum is 'the world' from the perspective of an external observer describing meaningless structure. The sentient stratum is awareness, that is an intuition of 'here and now'. It is actuality, thus concrete (transcendental) meaning through and through. The sapient stratum involves reflective thought. It deals with abstract con- cepts defined in terms of abstract concepts. Concrete meaning is not involved, it is not actual but remote inference. A mystery is a fact of life that has no reason. Facts of life reside in sentience, reasons in sapience. A Platonic object is a formal concept without related intuitive content. Formal concepts reside in sapience, intuitions in sentience." These strata are modeled also from a mathematical/formal point of view in such a way that the work of Koenderink-van Doorn fully falls within the Petitot's naturalization perspective.

Giovanna Citti and Alessandro Sarti provide a contribution to the volume by extending the Petitotian neurogeometric approach to more complex functional architectures built as a sequence of contactization and symplectization process. After recalling the history of the neurogeometrical problem, authors reconsider the classical neurogeometrical approach and extend it to describe the modularity of the visual cortex. Particularly they consider subsequent *contactization* and *symplectization* procedures to model the functional architecture of different cortical layers and families

of cells. This approach is compatible with neurophysiological models proposed by Hubel and Wiesel. In fact they introduced a type of wiring which could produce a simple-cell receptive field starting from an alignment of retinal cells with radially symmetric receptive field. A similar type of wiring, produces a complex cell, starting from an alignment of simple cells. So a modular way to assemble receptive profiles and produce cortico-cortical connectivity is at stake. This can be mathematized as a sequence of geometrical/topological operations to build contact and symplectic structures.

Of course, as it emerges from the aforementioned papers, the activity of schematization and modeling deeply concerns the process of creation in mathematics. For this reason the Neurogeometry section is preceded by a chapter about objectivity and meaning in Mathematics, hosting the papers of the mathematicians Bernard Teissier, Alain Chenciner and Daniel Bennequin.

The topic faced by Bernard Teissier deals namely with cognition from the point of view of the process of creation in mathematics. The title of his contribution "On objectivity and meaning in Mathematics" is apparently provocative since mathematics is considered by most to be the quintessence of objectivity. The paper "explores the consequences of distinguishing the foundations of meaning and the foundations of truth in mathematical statements, or imagination and rigor as motors of mathematical development. The foundations of meaning can be sought in our largely unconscious perception of the world, which modern cognitive science is exploring." In a second part, the author compares two approaches to understanding mathematical problems: "creating appropriate abstract structures or creating geometric models where we can use our intuition of space".

A reflexion about objectivity and meaning is also at the center of the paper of Alain Chenciner that develops around two sentences by René Thom: "Ce qui limite le vrai, ce n'est pas le faux, c'est l'insignifiant" (What limits the true is not the false, it is the insignificant) and "Tout ce qui est rigoureux est insignifiant" (Everything that is rigorous is insignificant). The argumentation shows the inconsistency of the Hilbert program of logic axiomatization of mathematics and any temptative to exclude signification from the mathematical practice. In "fact the semantic acceptability of an assertion is a problem ontologically prior to that of its truth. Truth presupposes meaning. The ideal of logicians (and certain mathematicians) of eliminating meaning in favor of truth alone is a philosophical contradiction".

Daniel Bennequin too faces the problem of the nature of Meaning from the mathematical point of view and proposes models of neural networks based on Grothendieck categories (topos, stacks) and Thom topological dynamics (singularities).

1.3 Semiotics and Aesthetics

The first dynamic models in human sciences were introduced by René Thom and Christopher Zeeman at the end of the 1960s. They essentially concerned perception, language and cognition.The main idea here consist in modeling the content of a

mental representation as an attractor of an appropriate neural dynamic. There is here a double temporality: the temporal flow of mental dynamics and a the temporal axis of control that is a slow dynamic operating on these rapid dynamics. Mental events are then bifurcations of attractors, controlled by the slow dynamics. What's more, Thom and Zeeman had shown how by using order parameters (average activities) we could drastically reduce the number of degrees of freedom of the neural modules considered. This micro-macro transition can be interpreted as a change in level of reality, from the neuronal level to the psychological one.

Petitot extended morphodynamic models on the one hand to categorical perception in phonetics and on the other hand in semio-linguistics [10, 11].

Regarding phonetic perception, Petitot established the link with the tradition of structural phonology, from Ferdinand de Saussure to Roman Jakobson. Regarding semio-linguistics, he modeled the attantial structures constituting semio-narrative structures in the sense of Greimas [8, 9, 13].

In relation to the work of Per Aage Brandt (Univ. of Aarhus), the link was made with cognitive grammars. This led Petitot to take up structural approaches to syntax such as that of Lucien Tesnière as well as the tradition of case grammars, from Louis Hjelmslev to Charles Fillmore. Much work has been devoted to the "rise" of perception towards language. This led to the development of a topologico-dynamic, schematic and iconic conception of grammar which is radically opposed to the Chomskyan formalist conception: Cognitive Grammar by Ronald Langacker, Cognitive Topology by George Lakoff, connectionist models of learning the prepositional systems of different languages by Terry Regier, and, above all, neo-Gestaltist designs by Leonard Talmy.

For example, the spatial relations between objects linguistically coded by prepositions (in, above, through, etc.) are of an abstract perceptual nature (i.e. perceptivo-semantic) and can be categorized by specific topological relations. Their categorization mixes in a complicated (and still not well understood) way geometric information and categorical information. Developing a good mathematical model is considered one of the basic problems of cognitive grammars. Based on previous work on morphologies, Petitot has built, in collaboration with René Doursat, the first program capable of automatically applying certain prepositions to visual scenes [33].

Petitot also applied morphodynamics to the modeling of one of the keys to structuralist theory in anthropology, namely the canonical formula of myth proposed by Claude Levi-Strauss [12, 19]. This theme has been developed further particularly thanks to the work of Lucien Scubla, Pierre Maranda and Solomon Marcus.

The Section devoted to semiotics in this volume is opened by Ivan Darrault-Harris. His contribution recall "the double career of Jean Petitot, first as a polytechnician in the mathematical field with prestigious professors (Laurent Schwartz and René Thom), and then in his enthusiastic discovery of Greimas's semiotics, in which he found"...all the qualities that (he) appreciated in mathematics: inflexible rigor, a keen sense of the theoretical, a concern for formalization". At stake it was to challenge the canyon separating the exact sciences from the humanities.

The integration of the structural approach to semiotics and the catastrophe theory of René Thom makes emerge as important outcome the "naturalization of semiotics",

that is the topic of the intervention of Wolfgang Wildgen in the volume. This paper contextualizes the historical emergence of semiotic naturalization and outlines the relevant differences in the use of mathematical tools among Jean Petitot, Per Aage Brandt and Wildgen himself.

David Piotrowski's paper enlarges the domain of naturalization of semiotics dealing with the very specific problem of the constitution of sign in Saussurian semiotics. He shows how the Saussurian sign is defined by a system of negative oppositions that can be naturalized as morphodynamical devices, namely Thomian catastrophes.

Claudio Paolucci's contribution is a very affectionate tribute towards Jean and his relationships with the semiotic school of Umberto Eco. Starting from his experience as a young student who followed Jean Petitot's seminars, Claudio illustrates three fundamental contributions by Jean Petitot to Semiotics: From the idea of space as the pure intuition of structuralism, able to resolve a genuinely semio-linguistic problem, to new anthropological dimensions in narratives, and finally to the birth of cognitive semiotics. Claudio shows how "Morphogenesis of Meaning" dedicated to Greimas's generative path contains already all these ideas and it is in absolute the most important work of Jean Petitot as semiotician.

The two chapters of Peer F. Bundgaard and Stefania Caliandro deal with aesthetics and visual semiotics, i.e. the process of construction of meaning in vision, also in its relation with artworks. In case of Peer F. Bundgaard meaning is carried by the constitution of morphologies such as perceptual grouping, exploitation of shape dynamics and use of non-generic viewpoints. These purely visual structures constitute the qualitative ontology of a picture that informs and guides visual perception. In this way art is based on but also allows to discover grounding principles of visual perception. Stefania Caliandro bases her intervention on morphodynamics but is interested in plastic morphologies more than in topology or structural dynamics. The idea of Caliandro is to correlate the plastic to aesthesia, that is, conceiving the plasticity within the aesthesic comprehension of the sensitive. She aims to rediscover the morphodynamics of the perceived, the phenomenality of the picture to understand how complex dynamics are embedded in the work of art.

1.4 Epistemology and Phenomenology

In Petitot's discourse the concept of form plays an essential role mediating between physical objectivity and phenomenological manifestation. Hence the relevance of taking up the theories of form from a philosophical point of view. Thus, whether they are sensitive forms, spatio-temporal forms or more abstract forms in control spaces, a form is phenomenologically described as a set of qualitative discontinuities on a substrate space. This idea was formalized by René Thom and extended by Petitot to the study of a number of philosophers of form, in particular Kant, Goethe and Husserl [18, 25]. A philosophy of mathematics and a physico-mathematical objectivity leaves wide open the phenomenological problematic of the world of common sense as it manifests itself to us through perceptual apprehension and linguistic description.

However, this common world is essentially the one of cognitive sciences study. Hence the interest in a philosophical understanding of the link between these two dimensions of reality. From a mathematical point of view it means to understand the passage from a morphological description of forms to the topological modeling of the set of qualitative discontinuities, that is the underlying grammar of every phenomenon.

If the phenomenon is visual then the main issue will be to understand how visual information coming from the exterior world is processed and is coded by neural mechanisms. Phenomenological consciousness is then the correlate of the projection of the exterior world in neural structures. But the phenomenon can be very diverse from a visual form and anyway it can be traced back to a pheno-physics. As Petitot outlines in [14], "The main idea is to make the hypothesis that, at each point w of the material substrate W, there exists a physical process determining a local regime (analogous to a thermodynamic phase). These local regimes manifest themselves phenomenologically (like the phases) through sensitive qualities. The morphologies generated by qualitative discontinuities are then treated as the analogue of phase transitions. Emerging from the physical "interiority" of the substrates, they are conveyed as "ecological" information by light, sound, etc. media, and are apprehended by the perceptual and cognitive system. It is on this basis that I can develop a pheno-physics which transforms itself into a realistic (ecological) phenomenology". In other words for every phenomenon it is possible to define his phase space and its partition in attractor domains. It is the topology of this partition that in Petitot discourse constitutes the structure of the phenomenon itself and the base for a philosophy of sensitive, spatio-temporal or abstract forms [14].

Different contributions in the present volume will illustrate the multifaceted epistemic work of Petitot.

Jean-Michel Roy in his paper pursue a line of reflection he started to elaborate with Jean Petitot in the context of the research group Phenomenology and Cognition, that was created at Petitot's initiative and that they ran together for a few years in the early 1990s with the additional participation of Bernard Pachoud and the later one of Francisco Varela. The cooperation of the four researchers lead to the publication of the well known volume "Naturalizing Phenomenology: issues in contemporary Phenomenology and Cognitive Science". Roy presents here an original and very theoretical paper of philosophy of cognitive science, facing the fundamental topic of cognitive representationalism.

Giuseppe Longo recalls and analyzes another seminar, the one of "Geometry and Cognition" that he organized with Jean Petitot and Bernard Teissier in the years 1999–2000. Longo outlines how this project was focused on the link between geometry and cognition, in a double movement:

(1) From Cognition to Geometry: or the cognitive foundations of Mathematics (where in "cognitive" we also want to include evolution conceptual construction and its history);
(2) From Geometry to Cognition: or the mathematical analysis of human cognition (vision, in particular).

The consequences were both technical and epistemological:

(1) A better understanding of the role of these advances in natural sciences and cognition in the analysis of certain fundamental problems of mathematics traditionally considered philosophical;
(2) The development of certain aspects of Differential Geometry and a new role of Geometry in Computer Science.

Sara Franceschelli in her contribution "The delicate frontier between schematism and reflection" face the important topic of Semiophysics in Petitot works. Semiophysics is considered as a form of natural philosophy and is concerned with the seeking out of significant forms; it aims at building a general theory of intelligibility. The neologism is inspired by an expression used by Jean Petitot in Morphogenesis of Meaning, concerning the use of models of catastrophe theory as a "physique du sens".

On the other side Francesco Di Iorio recall the value of Kantian critical rationalism and outlines how Petitot renews and actualizes Kant's transcendental philosophy. He shows us how this philosophy matches modern fundamental physics, complexity theory, Thom's morphodynamics, enactive cognitive science, the idea that the mind is a complex self-organizing system, and the naturalization of the forms of perception, action, and language.

1.5 Selected List of Publications of Jean Petitot

As anticipated, I hope to do something useful by collecting an annotated bibliography of Jean Petitot's work in the research domains we are dealing with in this volume, which does not intend to be exhaustive of his work, but only to give an idea of the disciplinary extension of his research, perhaps to urge the curious reader to pick up the original books and continue his work.

1.5.1 Authored Books

- 1982. Pour un Schématisme de la Structure: de quelques implications sémiotiques de la théorie des catastrophes, 4 vol., Thèse, Ecole des Hautes Etudes en Sciences Sociales, Paris.
- 1985. Les Catastrophes de la Parole. De Roman Jakobson à René Thom, Maloine, Paris.
- 1985. Morphogenèse du Sens. Pour un Schématisme de la Structure, Presses Universitaires de France, Paris.
- 1990. Morfogenesi del Senso. Per uno schematismo della struttura, (trad. a cura del DAMS di U. Eco), Bompiani, Milano.

- 1991. La Philosophie transcendantale et le problème de l'Objectivité, Entretiens du Centre Sèvres, (F. Marty ed.), Paris, Editions Osiris.
- 1992. Physique du Sens, Editions du CNRS, Paris.
- 2003. Morphologie et Esthétique, Maisonneuve et Larose, Paris.
- 2003. Morphogenesis of Meaning (trans. F. Manjali), Peter Lang, Berne.
- 2008. Neurogéométrie de la vision. Modèles mathématiques et physiques des architectures fonctionnelles, Les Editions de l'Ecole Polytechnique, Distribution Ellipses, Paris. Version pdf.
- 2009. Per un nuovo illuminismo. La conoscenza scientifica come valore culturale e civile (trad. F. Minazzi), Milano, Bompiani (Il campo semiotico, a cura di Umberto Eco).
- 2011. Cognitive Morphodynamics. Dynamical Morphological Models of Constituency in Perception and Syntax (with R. Doursat), Peter Lang, Bern.
- 2017. Elements of Neurogeometry. Functional Architectures of Vision, Lecture Notes in Morphogenesis, Springer, 2017. ISBN 978-3-319-65589-5

1.5.2 Edited Books

- 1988 (ed.). Logos et Théorie des Catastrophes, Colloque de Cerisy à partir de l'oeuvre de RenéThom, Editions Patino, Genève.
- 1990 (ed.). 1790–1990: Le destin de la philosophie transcendantale (autour de La Critique de la Faculté de Juger), Colloque de Cerisy.
- 1999 (ed. with F. Varela, J-M. Roy and B. Pachoud). Naturalizing Phenomenology: Issues in Contemporary Phenomenology and Cognitive Science, Stanford, Stanford University Press.
- 2000 (ed. with Paolo Fabbri). Au Nom du Sens, Colloque de Cerisy autour de l'oeuvre d'Umberto Eco, Paris, Grasset.
- 2001 (ed. with L. Scarantino). Sciences et Philosophie en France et en Italie entre les deux guerres, Biblioteca Europea, 23, Istituto Italiano per gli Studi Filosofici, Vivarium, Napoli.
- 2001 (ed. with P. Fabbri). Nel Nome del Senso, Sansoni, Milano.
- 2002 (ed. with F. Varela, J-M. Roy and B. Pachoud). Naturaliser la phénoménologie, CNRS Editions, Paris.
- 2009 (ed. with M. Bitbol and P. Kerszberg). Constituting Objectivity. Transcendental Perspectives on Modern Physics, The Western Ontario Series in Philosophy of Science, vol. 74, Springer.
- 2017 (ed. with M. Bitbol, A. Cohen, J.-P. Dupuy). Francisco Varela. Le cercle créateur. Ecrits (1976–2001), Le Seuil, Paris.
- 2017–2021 (ed. with A. Haefliger, M. Chaperon, A. Chenciner, J. Lannes, F. Laudenbach, B. Teissier, D. Trotman, P. Vogel), RenéThom. Ouvres mathématiques, volumes I, II, III, Société Mathématique de France.

1.5.3 Special Issues of Journals

- 1982. 'Aspects de la Conversion', Bulletin du Groupe de Recherches Sémio-Linguistique, V, 24, EHESS.
- 1989. 'Approches Morphodynamiques de la Sémiotique Cognitive', (P.A. Brandt, W. Wildgen, P. Ouellet, J. Petitot), Recherches Sémiotiques/ Semiotic Inquiry, 9, 1-2-3.
- 1990 (with M. Paty). 'Numéro spécial en l'honneur du Professeur L. Geymonat', (F. Minazzi, J. Proust, G. Heinzmann, M. Paty, J. Petitot, L. Boi, F. Barone), Fundamenta Scientiae, 10.
- 1990. 'Sciences Cognitives: quelques aspects problématiques', (J. Proust, J-P. Desclés, M. Piatelli-Palmarini, D. Andler, F. Varela, J. Petitot), Revue de Synthèse, 1/2.
- 1991 (with J-C. Coquet). 'L' Objet', (S.E. Larsen, J-C. Coquet, M-J. Borel, J-F. Bordron, J. Poulain, J-P. Desclés, J. Petitot), Langages , 103.
- 1995. 'Linguistique cognitive et Modèles Dynamiques', (Y-M. Visetti, T. van Gelder, R. Langacker, F. Manjali, P. Gá rdenfors, P-A. Brandt, P. Ouellet, W. Wildgen, D. Piotrowski, J. Petitot), Sémiotiques, 6–7 (Didier).
- 1995. 'Sciences cognitives et Phénoménologie', (J-M. Roy, B. Pachoud, J. Proust, E. Pacherie, J-L. Petit, M. Villela-Petit, W. Miskiewicz, J. Petitot), Archives de Philosophie, 58, 4.
- 1999. 'Géométrie et Vision', Mathématiques, Informatique et Sciences Humaines, 145, EHESS, Paris.
- 2000. 'Philosophie transcendantale et objectivité scientifique', Archives de Philosophie, Beauchesne, Paris.
- 2003 (ed. with J. Lorenceau). Neurogeometry and Visual Perception, Special Issue of the Journal of Physiology-Paris, 97, 2–3.
- 2009 (ed. with A. Sarti & G. Citti). Neuromathematics of vision, Special Issue of the Journal of Physiology-Paris, 103, 1–2.
- 2010 (ed. with P. Bundgaard). Aesthetic Cognition, Special Issue of Cognitive Semiotics, 5, 2010.

1.5.4 Papers

1.5.4.1 Neurogeometry, Cognitive Models, Networks, and Complex Systems

- 1974 (with P. Rosenstiehl). 'Automate asocial et systèmes acentrés', Communications, n. 22, 45–62, Paris.
- 1977. 'Centrato/Acentrato', Enciclopedê ia Einaudi, II, 894–954, Einaudi, Turin.
- 1984. 'Paradigme Catastrophique et Perception Catégorielle', Recherches Sémiotiques/Semiotic Inquiry, 3, 207–245.

- 1989. 'Morphodynamics and the Categorical Perception of Phonological Units', Theoretical Linguistics, 15, 1/2, 25–71.
- 1990. 'Le Physique, le Morphologique, le Symbolique. Remarques sur la Vision', Revue de Synthèse, 1–2, 139–183.
- 1991.'Why Connectionism is such a Good Thing. A Criticism of Fodor's and Pylyshyn's Criticism of Smolensky', Philosophica, 47, 1, 49–79.n.
- 1992. 'Cognition, Perception et Morphodynamique', La Représentation animale, (J. Gervet, P. Livet, A. Tê te eds.), 35–58, Presses Universitaires de Nancy.
- 1992. 'Modèles morphodynamiques de catégorisation phonétique', Sciences cognitives, Le Courrier du CNRS, 79, 90.
- 1993. 'Modeling: Formalization or Mathematization ? The example of the morphodynamical approach to language', Structures of Signification, vol. III, (H.S. Gill, ed.), New Dehli, Wiley Eastern, 700–709.
- 1994. 'Algorithmes perceptifs et modèles cognitifs', Science et Défense 94 (Bicentenaire de l'Ecole Polytechnique), Paris, Dunod.
- 1994. 'How can Physical Symbols Act upon Semiotic Structures and 'Visualized' Meanings?', "Bridging the Gap', Where Cognitive Science meets Literary Criticism', (Herbert Simon and Respondents, G. Guzeldere & St. Franchi eds.), Stanford Humanities Review, Suppl. vol. 4, n.1, 96–98.
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- 1997. 'Sheaf Mereology and Space Cognition', Modelli della Cognizione e Teoria della Complessità, La Nuova Critica, 29, 1, 49–74, Union Printing.
- 1998 (with Yannick Tondut). 'Géométrie de contact et champ d'association dans le cortex visuel', Rapport du CREA n. 9725, Ecole Polytechnique.
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- 1998. 'Modèles morphodynamiques de segmentation spatiale', Cahiers de Géographie du Québec, 42, 117, 335–347.
- 1999 (with Y. Tondut). 'Vers une Neuro-géométrie. Fibrations corticales, structures de contact et contours subjectifs modaux', Numéro spécial de Mathématiques, Informatique et Sciences Humaines, 145, 5–101, EHESS, Paris. http://jeanpetitot.com/ArticlesPDF/Petitot_NG_M & SH.pdf

- 2000. 'Il labirinto della complexità: dalle dinamiche neuronali alle categorie cognitive', Ruggiero Romano, l'Italia, l'Europa, l'America (A. Filippi ed.), Università degli Studi di Camerino.
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- 2003. 'Neurogéométrie et phénoménologie de la perception', Philosophie de la Perception (J. Bouveresse, J-J. Rosat, eds.), Collège de France-Odile Jacob, Paris, 53–76.
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- 2006. 'Entoptic vision and physicalist emergentism', Philosophical issues in psychiatry, Copenhagen, May 25–26, 2006.
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- 2008 (with A. Sarti and G. Citti). The symplectic structure of the primary visual cortex, Biological Cybernetics, 98 (2008) 33–48.
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- 2010. 'Neurogeometry and the Functional Architecture of Vision', Neurogeometria e cognizione visiva (A. Carsetti & A. Sarti eds), La Nuova Critica, 55–56 (2010) 11–22.
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- 2011. 'Neurogeometry of visual functional architectures', Lectures, CIRM 28/11/2011-02/12/2011
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- 2015 Varenne, F., Chaigneau, P., Petitot, P. & Doursat, R. 'Programming the emergence in morphogenetically architected complex systems', Acta Biotheoretica, 63(3) (2015) 295–308.
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- 2015. 'Actualité du rationalisme critique en sciences cognitives', Le rationalisme critique européen, Académie internationale de philosophie des sciences, Università degli Studi dellInsubria, Varese, 28–29 septembre 2015. Slides
- 2018. Calcul différentiel neuronal et architectures fonctionnelles, Les Neurosciences au sein des Sciences de la Cognition entre Neuroenthousiasme et Neuroscepticisme, (C. Monier et A. Sarti, eds), Intellectica, 69/1–2 (2018) 303–346.
- 2018. Structuraisme dynamique, Séminaire A. Sarti, EHESS, 18/12/2018.
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1.5.4.2 Physical Models

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- 2002. 'Mathematical Physics and Formalized Epistemology', Quantum Mechanics, Mathematics, Cognition and Action (M. Mugur-Schaechter, A. van der Merwe eds), Kluwer, Dordrecht, 73–102.
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1.5.4.3 Singularities, Morphodynamics, and Catastrophe Theory

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