The Modeling Process in Geography

From Determinism to Complexity

Edited by
Yves Guermond
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Foreword

The Taste for Measuring and Modeling

This book gives me the opportunity to reflect upon the reasons behind my complex relationship with mathematics, as well as the frustrations revealed by an insufficient deepening of the relationship between, on the one hand, the human and “interdisciplinary” geography that I practice, and, on the other hand, a question that remains fundamental: which models for which science?

The evidence of a taste…

Before analyzing the reasons that make me think that my use of the scientific practice referred to as “modeling” – of which I would have liked so much to be a part\(^1\) – has been insufficient, I must recall a few steps along my career that testify to this interest in quantification, that is, the concept of models and modeling.

First come the taste and need for measurements in order to identify facts and geographical processes, and to test the hypotheses used to understand them. Despite Hubert Béguin’s reply of “But how do you measure it!”, when I enthusiastically told about the content of my talk for the *VIIth European Colloquium on Theoretical and Quantitative Geography* in September 1991 in Hasseludden (Sweden), from the beginning, and guided by Ernest Labrousse, I have known that one way or another

\(^1\) In particular when Alain Pavé started, at the beginning of the 1990s, a special program in the Programme Environment of the CNRS, “Method Models, Theories”, whose results (along with others) led to a conference in 1996 *Tendances nouvelles en modélisation pour l’environnement*, Paris, CNRS, Actes des journées du Programme Environnement, Vie et Sociétés.
“everything can be measured” and must be for an assertion to be credible. Measuring is also at the center of politics, as attested by the responsibility given by Napoleon to the two scientists Chaptal and Montalivet, for collating the agricultural statistics of France.

The Tableaux de l’agriculture française with its previously unpublished maps (1966, 1968), the attempt to measure the degrees of urbanization at the scale of the départements (1973), the arrondissements (1971) and of a sample of undefined districts between rural and urban (1974), are proof of the early use of mathematics in building clever indicators revealing the unequal spatial distribution of situations evaluated through the complex indicators of density, urban frame and the combined dynamics of the demographic components of rural districts. During those years, following what I had been taught by Ernest Labrousse and then Pierre Coutin (2001), the link between mathematics and politics became obvious as an ordinary experience of social sciences researchers. This is how, attempting to translate Pierre Coutin’s prospective vision regarding the ways in which to modernize French agriculture while respecting the local and regional farming communities, Jean-Claude Bontron and myself have used standard deviation in order to theoretically calculate the “technically necessary agricultural population” in France, for each département, and to suggest to the Commissariat Général du Plan the objective of reducing the active agricultural population in equal proportion, calculated in relation to the level of overpopulation reached in each département.

You could say, as my colleague Denise Pumain did at the end of the 1970s, that I am “of the pioneer pre-quantitative generation”, because “it is not by using measurements, as cleverly as this may be done, that geography is theoretical and quantitative, but that it can rather be identified by what is defined by the term spatial analysis!”

Why was my way of using mathematics not theoretical? Was it because of an overly “applied” approach, as was said then? Yet, in my research on low-density areas, and still with the complicity of J.C. Bontron and Lucette Vélard, whose skills in statistical processing, multivariate analyses, and the ascending hierarchical classification method never ceased to grow, our aim was to test hypotheses concerning the functioning of these areas as a spatial system and to build a theory of the dynamics of the “reverse side” of urbanization processes! While these studies underlined measured spatial discontinuities2 (and were not ideological, as in La France du vide), at the same time as they highlighted (as pioneers, and going against the prevailing analysis techniques of the day) the fact that this level of organization

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and spatial structuring was not dependent on demographic evolution\(^3\), why was it that they not enter the canons of the theoretical and quantitative geography being built then.

Was it a matter of the cultural relationship with mathematics? Whatever the importance I granted to the dimension of data analysis in examining causes and effects hierarchically, it is true that I never used it exclusively. As was the case for the generation of which I was part, I had to distance myself with mathematical reasoning (the concept of modeling) and its top-down application to social and spatial facts. Above all, I had to confront what quantitative analysis proved in terms of what could be called the level of experiences, as suggested to me by P. Coutin, referring to Leplay, that is the experience of the complex object that are local monographs, field studies as models of a relationship system between populations and territories, between societies and living environments. This was probably the weakness in the eyes of Theoquant geographers looking for a science and purified spatial laws in the field.

Furthermore, in the 1980s, I sometimes used the concept of a model in a sense that diverted it from the mathematical or physical model. Among the various meanings of this term, I found it efficient and relevant to use the terms “prototype”, “object to imitate” or “exemplary”. Thus, the various situations of rural development politics at the local level that I had been observing from the 1970s until the end of the 1980s (rural planning schemes, national, then regional *pays* contracts), always complicated to analyze, appeared as being part of either one of two “models”, one based more on centrality and spatial equity, and the other “local”, i.e. giving free rein to the specific social dynamics of a territory. In this, it was both a model for analysis (for the researcher) and a model for action (for the politician). Once again, this multiple usage of the term and the incongruity of a quantified translation of this type of model led me away from the hard core of theoretical and quantitative geography.

**Modeling as a necessity…**

However, I was never discouraged, and the issue of method, the necessity of models and modeling to the study of complex objects has been a recurring motif of my research in the 1990s, when it took a clear turn towards environmental concerns. What was maybe only an “opinion”, or rather a “certainty”, then became the awareness of a necessity. The decision I made to research “complex objects” that

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\(^3\) Hence the notice taken, as early as 1975, of the reversal of the century-old tendency to exodus and depopulation in rural districts, as well as highlighting the importance of non-agricultural activities and jobs, and of the new living practices.
“cannot be decomposed and made simple without being modified, and their nature transformed, by the reductions used” is a decision that necessarily entails interdisciplinarity. The social issue of the environment reactivates the paradigm of society/nature relationships and requires the modeling of interactions between social systems, natural systems and technico-political systems within the complex object that is an environmental problem. In this case, the modeling can only be local, which, translated into geographical language, means that the identification of the relationships of the complex system is only valuable in their strict co-localization. Thus, the two epistemological requirements of geography linked to environmental issues: the revival of what I have called “inner interdisciplinarity”, meaning 1) a work articulated between physical geography and human geography; 2) the modeling *in situ* of processes with distinct natures and times specific to this type of object. Hence also the importance of tools such as the geo-referencing with a constant grid and GIS, or the imperative, for all disciplines, to work on the same microsite.

From the Observatory for ecological, economic and social changes in Causse/Cévennes which Marcel Jollivet was in charge of and in which I was in charge of coordinating the teams for Causse Méjan, to the Méjan Observatory that followed that first PIREN program “Co-evolutions of the dynamics of the natural environment and the society of Méjan cattle breeders: the bush progression” coordinated by Marianne Cohen, I have never ceased to assert, as did the whole group of border crossers (we must keep in mind that Jean-Marie Legay was the leader of this group on the natural sciences side) the absolute necessity of using all the methods and tools of modeling and GIS to study these crossover issues between social and natural sciences, while advocating internal interdisciplinarity in geography, that is the re-articulation of the systemic knowledge possessed by physical geographers with that of spatial analysis geographers that was, at the time, more widely used in human geography. It was obvious and I was certain that, whatever method was used to build the models, be it a deductive method (a theory $\Rightarrow$ a model $\Rightarrow$ a situation) as used by mathematicians, physicists, biophysicists, or even chemists and some geographers, or an ascending method (a situation $\Rightarrow$ a model $\Rightarrow$ a theory) for which agronomists and physicians know the difficulties linked to the constraining hypotheses imposed by the situation, and which I preferred due to my attachment to the field, it was truly the back and forth movement between model and field, “this to-and-fro between model and experimentation”, which is the core of the method used to highlight the functioning of a complex geographic object at the boundary of physical and social systems.
Reasons for dissatisfaction and incompletion…

However, there then crept into my research practice, subtly but inevitably, a dissociation between what I was expecting others to do, in particular young researchers I oversee or those who are part of research collectives that I am a part of, and what I would do myself, thereby leading me further and further away from mathematical and modeling skills. In other words, while I am convinced that, in order to be heuristic, the geography that studies the urban environment, risk management, territory sustainability - be it sustainable cities or neighborhoods, or agricultural systems or rural and periurban territories - must be both model-dependent and multidisciplinary, I myself tend more and more to position myself as an observer of what is brought into environmental research by modeling without immersing myself in the new modeling tools that keep invading that field (fractals, MAS and cellular automata etc.). While I recommend this methodological orientation and support those who apply it (who can be found in C. Soulard and W. Hucy’s work), while I even try through them to introduce with all its force the idea that spatial analysis methods are an aspect of “workshop site” programs that cannot be ignored and the aim of which is the cognitive and continuing observation of “eco-sociosystems”, I take a critical stance regarding some works in “spatial modeling” that, and I will come back to this, seem to me to be not only simplistic but antithetical to the complex objects they claim to be studying.

Out of respect for the way I am being welcomed, through this book, into the community of spatial analysis, I must decipher the undercurrents of this attitude bordering on schizophrenia. Thus I must first answer the question: is it a strictly personal issue, of a judgment cast on the way some people use modeling, or an awareness of the difficulties in “bringing together volunteers from all disciplines”, in particular those “good at math and modeling” in order to accomplish my own research ambitions?

Let us review these hypotheses one after the other. There is indeed, at the point of origin of this lack of enthusiasm in going from “pre-quantitative” to quantitative and model-based skills a matter of personal and theoretical perspective. Well trained in mathematics in high school, surrounded during my first research years by mathematicians and philosophers who reflected on the relationship between politics and sciences, mathematics and models4, I have come to think that mathematics does

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4 I am simply referring to my acquaintance in the 1960s-1970s with Louis Althusser and Alain Badiou at the École Normale Supérieure, they themselves being friends with Maurice Mathieu who was then a mathematician at the Collège de France in Perrin’s team. I am also referring to conversations with the mathematicians at the ENS, including Adrien Douady who was connected to the Bourbaki school (formalist, metamathematician, structuralist), but also Benzécri and Françoise Badiou.
not consist of taking reality as a starting point, since mathematicians (whose intuitive gift for formalization is often detected in their early childhood) make discoveries in abstraction or rather in a realm of reasoning that do not go beyond mathematics as a discipline. Nurtured on many anecdotes about the career of Sophie Germain, Poincaré, etc. that all showed how mathematical discoveries are ill-adapted to life in academic society and would rather be fitted with social isolation, it seemed to me hard, even impossible, to reconcile my taste for the social and current aspects of the world in which I was living (which had made me choose to join the CNRS as a geographer rather than a historian) with a deepening sense of the heuristic virtues of mathematics applied to geography. More than that, whenever, led by a then poorly defined intuition of the importance of multidisciplinarity in solving complex issues, I tried to engage the attention of my mathematician and/or philosopher friends, I was immediately faced with a negative judgment of my attempt. The arguments used against it were quite similar: either the critique was aimed at the conceptual perversity of modeling that I have referred to before, or based on harsh judgments of my first attempts at applying mathematics to social sciences, considered as simplistic and, lacking conceptualization, as unconsciously serving the dominant ideology. If, I was told, quantum physics has made progress thanks to mathematics and has helped mathematics evolved, it is because the level of conceptualization was maximum. By choosing to apply mathematics to my research, I was running the risk of weakening my theoretical capacity and my results through a mediocrity of mathematical foundation. In other words, it was better for me to deepen my hypotheses and build a system allowing a stronger conceptualization, rather than depend on already existing models and modelings (for instance regarding the processes of dissemination and polarization), which would modify my research goal, and maybe even put it under the influence of the then dominant ideology.

In short, from a personal perspective, doubt took hold: was I capable of being heavily involved, both in mathematics and geography, until I found the mathematical expression fitting each of my research objectives, which were oriented more and more towards the study of complex objects? This doubt was reinforced when I read Edgar Morin, who did not have to use mathematics in order to “introduce us to complex thought”, and this at the time when the “mathematics expert” Le Moigne joined him in his “theory of the general system” as a “theory of modeling”.

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5 I wanted to try and build a typology of farms in which I could integrate temporal processes (dynamics of the family and the reproduction of the farm) and spatial processes (layout of crop parcels, proximity and contiguity, etc.) See MATHIEU N., 1972, “Typologie dynamique d’exploitations agricoles des plateaux de Haute-Saône”, in Approche géographique des exploitations agricoles, Cahier no.1, Paris, April, pp. 9-24 (Équipe rurale du LA de Géographie Humaine).
What can be said, then, about my relationship to others, geographers or those close to geography, who deliberately committed themselves to a path I was not willing to follow? A retrospective piece of internal enquiry has led me to distinguish three attitudes towards them that may be linked to the way I evaluate differences in the epistemological, even the ethical scope of these practices. It is true that generally I had a positive prejudice regarding all those who embarked on the adventure of models and modeling. Being curious about all the accomplishments, about progress in geography, I have always made a point of participating in the Dupont Géopoint group and in the European conferences on theoretical and quantitative geography. However, and this I admit is the first position that I took, I am somewhat wary of those who, compulsive and eager to be regarded as the most effective in spatial analysis, seem to forget the meaning of the research objects whose systemic functioning they claim to analyze. To try out a new method in se and per se is more important for them than the cognitive goal which seems to me to be the core, the ultimate value of research. I do not need to dwell on the texts that have led to my theoretical wariness of this usage of models and modeling. It may be enough to refer to my outrage when I read that the best example of urban growth following the fractal model was the town of Nouakchott! Nouakchott, the city of all poverties, but also of all the craftiness of informal economy, exploited in the quest for survival! How could anyone call this growth, what was no more than the extension of a spatial form emptied of its social and human content? How, when the research was supposed to be theoretical and fundamental, could anyone thus simplify the city to the variable of developed sites and to a demographic dynamic? Was the craving for a “mathematically expressed” result and a rigorous proof antagonistic to the effort to think complexly, to bring to light the intricacies of elements and processes that form urban spatial systems? Of course, this is an extreme example that does not represent all the attempts at modeling which are more concerned about the social dimension of geography, and also more concerned about the relationship between physical processes and natural processes than such a simulation model allows. Yet, it is representative of a tendency to use a method for its own sake without insisting upon the results yielded being repositioned within the broader conceptualization of the research field and the discipline.

Although they are in a very different position from those mentioned above, certain well-used studies in the scientific milieu concerned with the environment and more specifically on the management of renewable resources also make me circumspect. Here is the second reason inhibiting my personal involvement in the use of modeling tools. From reading the journal Natures Sciences Sociétés, I cannot help but notice the current craze for “modeling as an accompanying tool” corollary to the valorization of “action research” (or “development research”), corollary also to praising the virtues of spatial modeling as a decision-making aid. New computer tools such as GIS, MAS, cellular automata, etc. that is to say artificial intelligence applied to localized (geographical, territorialized) complex situations, are at the core
of this type of modeling. This research trend is being used more and more in the big applied research institutions such as INRA\textsuperscript{6}, CIRAD\textsuperscript{7} or CEMAGREF\textsuperscript{8} and suggests models with joint “resource/exploitation” dynamics, between field and theory, that are supposed to both produce knowledge about complex systems and facilitate the dialog between users and the learning of collective decision making concerning the management of ecosystems and renewable resources. We may wonder if in this shift from systemic analysis to systemic modeling, and then the building of expert systems using computing modeling tools, there might be some confusion between what is called a mathematical model, which is supposed to be extremely reliable in its own realm of application, and mathematico-computing models that are supposed to simulate various dynamic behaviors (some of which cannot be expressed mathematically) in scripts that impact the spatial system. However, this is not really the issue since, as I have already mentioned, the conceptual clarification that comes from going back and forth between a situation (or an experience of reality) and the model built to explain it is in itself positive. What raises questions is the risk taken by these researchers, even when they do try to follow deontological principles of respect for participants who do not have scientific expertise, of missing out on certain scientific knowledge without which the “decisions” made by the actors can in no way be understood. Who are the “actors”? What does it mean to make a decision? What is the meaning of territory in the simulation? What do “landscape dynamics” mean to the researcher in the simulation model and in the mind of the people to whom it is presented, and from whom a decision, or even a consensus is expected? In other words, once again, the risk of simplifying complexity to the point of misrepresenting the object regarding which a decision must be made, is important. Is obtaining a consensus with the use of scripts simulating consequences not a way of making use, as being blind, of those who are supposed to make decisions and about whom very little is being said? Once again, skills are considered as most important and weaken the awareness of being in a position of power. How could I not choose to be careful when confronting experiments already considered as models to help make decisions, and which I think are premature and insufficiently thought out in relation to the social stake they raise?

Thus, it is a matter of science partners and trust in a collective of researchers intent on studying a complex object even if, as is the case for the sustainable city, the study of the object depends on “social demand”, or even the well-being desired by its inhabitants. Here is the third reason for my relative neglect of spatial analysis and modeling. In order to overcome the criticism I just referred to, the only tenable

\textsuperscript{6} Institut National de Recherche Agronomique: National Institute for Agronomical Research.
\textsuperscript{7} Centre de coopération Internationale en Recherche Agronomique: Center for International Cooperation in Agronomical Research.
\textsuperscript{8} Institut de recherche pour l’ingénierie de l’agriculture et de l’environnement: public agricultural and environmental research institute.
position, on the theoretical and practical levels, is to be certain I am part of a multidisciplinary team aware of the skills of everyone, and its complementarities. As I have written earlier, interdisciplinarity is a practice in which, step-by-step, a conceptual approach and a multidisciplinary research plan is built around a complex object, the study of which is of equal interest to all scientific partners. For us geographers, it is often an issue involving interactions between natural systems and social systems (for instance, flooding risks due to erosive run-off, or the management of biodiversity in an urban environment, etc.). This type of complex issue requires a broadened multidisciplinarity, at least between physical geographers and human geographers, which is still an exceptional occurrence. Modeling no doubt has a place, but not exclusively, as must be the case for all disciplines involved, and above all, under the condition that it is introduced when the problem is very clearly expressed and the need to model is clearly identified, and also when, as mentioned before, there is a to-and-fro between the model (modeling) and the experience (field work), the latter being defined as “any organized way of acquiring information that includes, in the perspective of an expressed goal, a confrontation of reality”.

However this internal interdisciplinarity in geography aiming to build a common approach to spatial analysis, social geography and physical geography, is still a utopia. Not that I underestimate the results obtained in the Causse Méjean Observatory! Not that I deny the forward strides of the MTG group, in particular around Daniel Delahaye, in articulating physical issues and social dimension! But the interdisciplinary practice in geography, as I have tried to define it, is still a minority, and its results are still too meager. Each research group tries to innovate within its own activity, with its scientific capital, without trying to move in terra incognita, or beyond its recognized horizons. As I did when I was part of MTG and tried in vain to build a research program bringing together Patrice Langlois and Marianne Cohen, I still regret that a more vigorous work is not being implemented between our two laboratories in order to think together about the place of modeling in the advances of our research.

The acceptance of a conceptual modeling based on the statement of an interaction system

While at the onset of this reflection I pointed to the incongruity of my being one of the authors of this book, I find myself able to conclude a conciliating approach that would reinvigorate the dialog between the “modeling and graphic processing” and “social dynamics and recomposition of space” laboratories, precisely on the subject of modeling in geography. My suggestion is a mutual recognition of the importance of conceptualizing the issue to be studied before using models and modeling. Indeed, I think that in the research school to which I belong, the
enunciating of hypotheses regarding the interaction between elements whose mutual connection is not obvious, in particular interactions between social and spatial practices and natural elements, should be taken into account. This logical statement of the relationships between natural systems and social systems relies on the identification and the construction of concepts that can open mediation in these relationships (for instance, the practice/representation duo, or the concept of mode of inhabitance). The logical statement also has a temporal value and must articulate the various temporalities of nature and society. These properties are found in the “heuristic research model on sustainable development” suggested by Monique Barrué-Pastor: examining all the terms of the relationship; discussing notions down to the definition of useful concepts; building a hierarchy of concepts and relationships, etc. Enunciating a relationship system seems to me to be a scientific result, but that is not really recognized by the specialists of spatial analysis and modeling because it is a conceptual approach that cannot be immediately translated into measuring methods that do not immediately call for a certain already tested model. Would it not be a worthy intellectual adventure to bring together means of thought that, in the end, leaves a large place to the conceptualization of a complex system?

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In a book published in 2007, Lena Sanders [SAN 07] revealed the great variety of choices made by geographers in the field of spatial analysis modeling. Our aim is not to produce a new inventory, but to propose general reflections about the realizations and perspectives of modeling research, both in the field of theoretical geography and in the field of applied geography in town and country planning. The tools are widely available, and are continuously improving, for spatial analysis as well as for geographic information systems. The MTG research group (models and graphic processing in geography) was created in 1986, with the ambitious target of keeping “close control of the new technical tools, with a permanent link to social demand, and to discover all the opportunities of interface between science and technology”. These 20 years of collective research have now given us an opportunity to propose this “reflection”. The chapters below are the work of researchers currently working in the laboratory, as well as former members of the initial team, who are now working in other universities.

The first two chapters situate our research program: what does a modeling process mean, and what is the specificity of this process in the field of human and social sciences? The path covered since the early realizations of spatial analysis is a basis from which new research has developed, mainly in terms of simulation techniques, thanks to recent computing developments.

In Chapters 3 to 8, we see how these models are confronted with the reality of what geographers are being asked to do in the field of land planning and management: cultural policy, territorial forecasting, socio-spatial segregation, inequity of regional dynamics, polarization, enclosing. Geography is, by definition, engaged in a process of understanding the relationship between society and space, but these confrontations with material work must not occlude the importance of a permanent evolving theory.
Towards that aim, the final chapters make it clear that some distance is necessary in responding to social demand, to enhance a new reflection on the fundamental concepts structuring the discipline, as well as the weaving of new links with the present level of science and technology. This distance is the only means of progressing towards the new horizons of a theoretical geography allowing numerical experimentation, or, in other words, an “artificial geography”. However, this research is only valuable if it prevents a retreat into previously tested methods. By keeping a concern for a constant reference to socially suitable themes, this reflection must allow methodological transfers towards the social agents. This to-and-fro gives its value to theoretical geography and prevents the interpretation models of the social life from staying set.

Bibliography

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Yves Guermond
Chapter 1

The Place of Both the Model and Modeling in HSS

The aim of this chapter is to present a few points of view on the concept of the model or on the modeling process. In Human and Social Sciences (HSS), modeling can cause some specific problems because of the immersion of the human researcher in his object of study, which is equally human. Our goal is to show the specificity of modeling in HSS, and the conditions of its utilization. The rigor with which the modeler will demonstrate the conditions of use of his own tool will allow the precision of the field of its utility in HSS.

It is helpful to specify the definition of the model and modeling utilization because of the different assertions in common sense, but also in HSS. The same definition in the same discipline can hide paradigms, methodologies and different issues, diverging or contradictory. The same theoretical posture in two different disciplines can lead to the use of two different words.

We will thus start from the definition that common sense gives to the word “model”. This is the object from the beginning. Modeling being used most often to mathematically formalize a reality, we will explore the notion of a model in mathematics. Modeling’s different utilities and issues in social sciences will thus be examined before putting them in perspective with mathematical language.
1.1. Models and modeling: definitions

The term “modeling” means both the activity required to produce a model as well as the result of this activity. From this distinction, the concept of modeling is larger than that of the model as it corresponds to the human activity producing a finished model, while the model is an object (concrete or abstract), voluntarily drawn from the activity. The model does not appear all of a sudden at the end of the modeling activity, it is progressively formed like a vase from the hands of a potter. It establishes itself in an activity, without identifying itself with it, it existed before (during the conception phase), it exists during the utilization phase, it exists even after its rejection, or in the will to create a better model, one which surpasses the first.

First we discuss definitions of the word “model”.

Among the many definitions in the Encyclopedia Britannica, we will retain two:

1. on the one hand, a “model” is a “formalized structure to realize a set of phenomena, which between them possess certain links”. In the mathematical model, this is the case defined as a mathematical representation of a physical, economical and human phenomenon...;

2. on the other hand, a model is a “schematic representation of a process, of a sound approach”.

These two definitions are on different levels; however they still possess certain connections.

The first definition is associated with the relation in the middle of a structure. It implies two notions: that of totality and that of interdependence between elements which is not the result of accidental accumulations. Thus, in this definition, the use of models would consist of “taking the totalizing attitude in any case”, as with what Sartre says about structuralism [SAR 60]. The catchphrase would be: “We don’t know if what we say is true, but we know that it makes sense.” This definition also returns to the system’s notion addressed in Chapter 11. In this category (the structure-model) a mathematical sense is given to the term “model”.

In the second definition, we can use the example of the geographical map. This is also the case for a Conceptual Data Model (CDM) in the framework of the elaboration of a database. However, we must acknowledge that the schematic-model is not a long way from the first definition, in as much that “a schematic representation” can very well be a graphical representation of the formalized structure returning back to the first definition. Frequently we associate a verbal formalization (like in mathematics, physics, chemistry, geography, etc.); a graphical