The System Dynamics Concepts of Model

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ABSTRACT

When modeling and simulation in System Dynamics, we can find many different uses of the term "model". Although these uses are very interrelated among them, and with other uses this term has in science, technology and philosophy, they serve to very specific and diverse goals and purposes. This paper tries to sketch a general framework in order to analize that wide variety of uses the term "model" has in System Dynamics. Sometimes, the differences among some of these uses will be so important that more than different uses of a term associated with a single concept, we could speak of different and mutually irreductible concepts. Nevertheless, whether these uses of the term "model" are associated with a single underlying concept or with different concepts, all of them are perfectly integrated in System Dynamics. Our point is that this is one of the main sources of its great success for making clear our ideas and for managing our actions trought complexity.

1- Introduction: terms, concepts, and uses

First of all, we think necessary to say a few words on the differences, from the point of view of the philosophy of language, among terms, concepts and uses. Terms belong to the grammar of a language, concepts belong to its semantics and uses to its pragmatics. The grammar of a language is composed by its alphabet, its vocabulary, and its sintaxis. Grammar is the right place where types and tokens of terms are identified. By definition, primitive terms of an alphabet cannot be but gramatically correct. All other terms can be gramatically correct or incorrect and more or less complex. Semantics only appears through the interpretation of a language. Roughly, concepts are the meanings of the terms of a language. Philosophers, psychologists, linguistics and computer scientists discuse whether meanings fix the reference of these terms by means of necessary and sufficient conditions, or by means of prototypes with similarity conditions associated, or by means of any other procedure. As an example of this, we can see Rosenberg & Travis (1987) and Schiffer (1987). It is also disputed which is the ontological place of meanings: are they social, psychological or platonic objects?. See Block (1980), Lycan (1990) and Haugeland (1985) for recent and interesting reviews of these issues. In any case, if we understand concepts as meanings, they are not linguistic entities of the same sort terms are. Concepts are not used either. What are used are the languages or, more properly, certain of the terms of some languages. Really, concepts and uses are related, but this relation is not direct. On the one hand, uses of the terms of a language are actions, and these actions can be very different depending on the goals and purposes. This topic has constituted one of the most interesting branches of recent linguistics and philosophy of language. See, for instance, Austin (1962) and Searle (1969). Only the declarative uses of the terms of a language are directly linked with the meanings these terms can have and, therefore, with the concepts these terms can express. On the other hand, especially in the case of our natural languages, concepts are selected by the way in which terms are used with declarative purposes. We identify these concepts by interpreting the language in relation to how it is used. When we face a language in use, the determination of the involved concepts always needs a hard work of interpretation and rational reconstruction. That interpretation and rational reconstruction must do justice to the intended declarative use of the terms of the language, but it must also permit to criticize some of these uses as incorrect ones. This strategy, known as "reflective equilibrium" in the ambit of analytical philosophy, is well expoused and defended by Goodman (1973), Rawls (1971), and Sosa (1991).

These distintions that we have just made are relevant to our topic. When in System Dynamics we say that we have a model, that we want to build a model, that a model is used in some way, and so on, we are applying to something certain term, the term "model", and we use this term to express some intended concept.

2- The uses and concepts associated with the term "model" in everyday, scientific, technological, and philosophical languages

The term "model", including here all its derivates, appears very often in our everyday, scientifical, technological, and philosophical languages. To begin with, let us consider three of the most prominent uses of the term "model" in everyday language:

(1) "Model" can be used referred to an object of representation or copy. So, we can say "to copy a model", or "to pose as a model for an artist", etc.

(2) "Model" can also be used referred to a representation, design, project, mold, plan, etc., of something. So, we can say "to model an object", or "to make a model of something", or "to create new political or economical models", or "theoretic models", etc.

(3) "Model" can be used referred to an special example or pattern of imitation in matters of knowledge or practical behavior. So, we could speak of "serving as a model", "taking someone as a model of virtue", even "being a top model".

In the scientific languages, the term "model", and all its derivates, appears and it is used in three main contexts: in the context of the presentation and use of any scientifical knowledge, in the empirical context of the cognitive science, and in the formal context of the logical and mathematical model-theory. In the first general context, it is possible to distinguish the following uses:

(4) "Model" can be used referred to particular selected examples of a general set of rules or theory. So, we can talk about the solar system, about the pendulous, about the tides, etc., as particular "models" of classical mechanics, or about a particular system of human relations as a particular "model" of some theory of social choice, etc. Examples of this use can be found in Suppes (1960), Sneed (1971) and Stegmuller (1979).

(5) "Model" can be used referred to pieces of relevant scientific knowledge or to sets of algorithms or rules that, having not properly the status of theories, because they are something less than theories, are very useful in order to articulate, systematize and make operative the scientific work. Examples of this use can also be found in Suppes (1960).

(6) "Model" can be used as a term synonimous of "theory", as it happens very often in the social sciences.

(7) "Model" can be used referred to a set of interelated theories or, including practiques too, that is institutional and ideological affairs and so on, referred to what has been called a "paradigm". This is usual in the works of historians of sciences.

In the empirical context of cognitive science, the term model appears as a theoretical term of a set of theories that oppose their concept of "mental model" to the concepts of "schema" "script", "frame", etc., developed by Minsky (1975), Schank and Abelson (1977), Rumerlhart (1980) and others, which have been extremely influential in cognitive psychology and artificial intelligence. The main references to mental models in this context are Johnson-Laird (1983), Schank (1982) and Holland J. et al. (1989). Brehmer (1989) makes some references to this concept of mental model from System Dynamics. Nowadays, these theories are not rigourously defined, but they are one of the most prominent alternatives in the recent cognitive science. We can summarize the use of term "model" in this context as follows:

(8) "Model" can be used referred to the sort of dynamical and ruled-based internal representations that a psychological subject is able to make from parts of its environment and of itself as integrated in its environment.

In the formal context we have indicated, the term "model" also appears as a theoretical term of a concret theory. In this case, the term is introduced more precisely and defined because the theory is not empirical but formal: this is the mathematical and logical "model-theory". This theory was initiated by Alfred Tarski and others in the 1950s and constitutes one of the main branches of the actual mathematical logic. See, Tarski (1953) and, for a more recent presentation, Chang, C. & H. Keister (1973).

(9) "Model" in the context of model-theory is used referred to a domain of objects which made true (according to some explicited and precises stipulations make by that model-theory) a set of statements of a formal language always with respect to an interpretation of this language in that domain of objects.

Scientific uses of the term "model" in these contexts are related with our everyday ones in the following way: uses 4 and 9 express a concept similar to the concept expressed by 1, and uses 5, 6, 7, 8 and 9 express a concept similar to the concept expressed by 2.

In <u>technological languages</u>, we have more ambiguity. The main uses of the term "model" in technology are:

(10) "Model" can be used referred to certain material objects made with the purpose to offer a concret perspective of a design or project, perhaps not completely understood, or described only from a theoretical point of view. The term "model" and its derivates can be replaced here for the terms "prototype", "map", etc.

(11) "Model" can be used referred to pieces of relevant knowledge, scientific or not, or to sets of algoritms, rules, computer programs, and so on, known or supposed as interesting and useful with respect to some topic.

(12) "Model" can be used referred to any specification or description of an object or system. Some formal theories about the processes of modeling and simulation in technology try to analyse that use. Zeigler (1976, 1984a and 1984b) is one of the more interesting ones. He considers a model as a possible specification of a system. Specifications could be made through systems of diferential equations, automata, etc. He proposes a general hierarchy of specifications. They beging with low levels of specification, as those of "black boxes", and goes up to rise specifications in the form of multicompoused systems. The bottom-up, top-down, and horizontal studies of those jerarquies show very interesting points about modeling, simulation, and the relationships between structures and behaviours. See Vázquez & Liz (1989).

(13) "Model" can be used to refer to certain material or conceptual objects with which help it is possible to solve certain problems of calculus and, in the end, certain practical problems. This use is very common in technology. For instance, in the field of artificial intelligence, Minsky (1968) wrote "We use the term "model" in the following sense: To an observer B, an object A* is a model of an object A to the extent that B can use A* to answer questions that interest him about A."

The technological uses of the term "model" overlap both the everyday uses and the scientific ones. Of course, up to a certain extent, the same could be said of the everyday and scientific uses, but the situation is not exactly the same. With respect to the concrete term "model", technological uses are more parasitic from the everyday and scientific ones than the seconds are from the formers. Technological use 10 is conceptually related with scientific uses 4 and 9, and with everyday use 1. Technological uses 11 and 12 are related with scientific uses 5, 6, 7 and 8, and with everyday use 2. Finally, technological use 13 is in some indirect way related with scientific use 5, but it is strongly connected with everyday use 3. Uses 10, 12 and 13 are typically technological. We should note the following. First, in 10 we have something like the converse concept that is expresed by scientific uses 4, 9 and by everyday use 1. In 4, 9 and 1 the objects are given, in 10 the objects are built. Second, in 12 but not in scientific uses 5, 6, 7 and 8, the strict scientific descriptive components are not necessarilly present. 12 is closer to 2 than to strict scientific uses of "model". Third, technological use 13 involves the need to solve practical problems with the help of material or conceptual objects which are called "models". This use of "model" is not present in science and go directly to everyday use 3.

Finally, in philosophical languages the term "model", and its derivates, is mainly used in a methatheoretic sense. It is used in order to make clear what can be its proper meaning, especially in the fields of science and technology. In other words, it is used to describe and legislate its correct uses. From the seminal work of Suppes (1960) and through all the philosophy of science dedicated to the rigorous formalization of scientifical theories, see for instance Sneed (1971), there is a constant tendency to asimilate and reduce all the uses of "model" to the precisse use that this term has in the model-theory. According to this perspective, there is only a concept that all uses of "model" intend or must intend to express, the concept referred by our use 9. This use is pretty close to use 4 and, in certain sense, to use 10, and the same concept is intuitivelly referred also by everyday use 1. Other uses must be reconstructed with relation to that basic one. And all differences of meaning must lie in the situations of uses of the term "model", not in the very concept expressed by the term itself. For instance, use 6 will be superfluous if actually there is a theory, and if there is not such a theory, use 6 must be analogous to uses 5 or 7. This was the radical explicit thesis maintained by Suppes (1960). What happen with uses like 5, 7, 8, 11, 12, linked to everyday use 2?. A possible direct answer can be found in Mosterin (1984). According to him, "system A serves as a model of system B for subject h if and only if 1) A is simpler or more known for h than B, 2) h developes (or could do it) a theory T from A, and A is a model of T in the sense of the model-theory, and 3) B is also a model of T in the sense of the model-theory".

The sort of objects that can be models in the sense of the model theory is so wide that there is no problem in considering both a real system and a numerical or linguistic description of it as models of certain theory T. But, in spite of this, the problem is that even if we accept all that sort of sugestions and reconstructions for uses 2, 4, 5, 6, 7, 8, 10, 11, and 12, it is very odd to try to do the same with uses 3 and 13. These uses have and irreductible practical component. The main point is that the conceptual or material objects that are called here "models" have an unavoidable reference to the actions a subject is able to perform with their help. Going back to 13 and seeing again the characterization that Minsky (1968) gives of these models, to find out that sometimes, uses 5, 8 and 10 have also important practical components.

There is, in consequence, enough reasons to think that, even if uses 1, 2, 4, 5, 6, 7, 8, 9, 10, 11 and 12 of the term "model" express a single concept, a concept make precise by model-theoretic use 9, uses 3 and 13, and sometimes uses 5, 8 and 10 too, express a different concept, a concept in which the actions performed with the help of the so called "models" become fundamental. Let us call this concept the operational concept of model. And, there is also reasons to distinguish among uses in which a theory is or could be clearly involved from uses in which this is not so. This last distintion goes across 1, 2, 4, 5, 6, 7, 8, 9, 10, 11 and 12, and allows us to speak of two other concepts associated. Let us call them, respectively, the model-theoretical concept of model and the purelly representational concept of model.

Now, we dispose of some conceptual framework in order to analyse the uses and concepts associated with the term "model" in SD.

3- The uses and concepts associated with the term "model" in SD.

In SD there are theoretical developments and practical aplications related with everyday, scientific and technological knowledge. See Forrester (1986) and Vázquez, Liz & Aracil (1990). The term "model" is present everywhere in SD. In relation to some of the most complex expressions term "model" that appear in SD, we could distinguish, at least, the following uses: a)"mentalmodels"; b) "verbal or linguistic models"; c) "models expressed in causal diagrams"; d) "models expressed in Forrester's diagrams"; e) "models in a DYNAMO (or STELLA, or any other more basic, sofisticated or extended software) format"; f) "simple mathematical models", "models expressed by means of systems of equations", etc, and g) "cualitative models" or "more completed mathematical models".

The standard process of modelling and simulation goes from a) to g), perhaps omiting some of the steps or going through feed-back movements. The important point here is that generally we have no explicit and concrete theories with respect to which all these so called "models" can be models in relation to a model-theoretical concept of model.

Usually, we build models in SD just because we have not such theories. From this point of view, in all the uses of the term "model" in SD, we cannot mean but a purely representational concept of model. This is specially obvious if we realize that, at the end, the whole process of modelling and simulation in SD lays on mental models, the intuitive and fuzzy knowledge experts, or people in general, have about the systems that are modelled and simulated. See Forrester (1986), Meadows (1980), Randers (1980) and Vázquez, Liz & Aracil (1990).

But, we have another important point of view in SD. Our models are tools with which help we improve, manage and control our action. The conceptual or material objects mentioned in b), c), d), e), f) and g) interact with the so called "mental models". Mental models change with the experience and the discussion, and they also change through SD'modelling and simulation process. All the uses of the term "model" in SD are related with an operational concept of model.

Mental models ocuppy an important place in our analysis. If they were superfluous, we could have models in the sense of a model-theoretical concept of model, but we could not have models in the sense of an operational concept of model. Because mental models are not certainly superfluous in SD, our models are something less than models in the first sense, they are only purely representational models, and they are models in the second sense, they are models in the sense of an operational concept of model.

Actually, the term "mental model" in SD has all the ambiguity that this term has in everyday language. And this language makes impossible any attempt to impose definite meanings. We use "mental models" in all the everyday senses indicated in 1, 2 and 3. This has a lot of danger, but it is also one of the main sources of the value that the SD formal reconceptualizations have as tools for making clear our ideas and for managing successfully our actions trought complexity. Of course, futures developments in the cognitive sciences on models could make our mental models models of some psychological theory, in the sense of a model-theoretical concept of model, and therefore the three different concepts of model we have distinguish could be unified. But this would be to speak of the future, not of our real models.

4- Conclusions

In this paper we have distinguished three different concepts of the term "model": 1) a model-theoretical concept, 2) a purely representational concept, and 3) an operational concept. In SD, the term "model", and its derivates, should be associated with the second and the third of these concepts. The main reasons for this make reference to the special and unavoidable role played by mental models in SD.

REFERENCES

Andersen, D., G. Richarson and J. Sterman. 1990. System Dynamics'90, Massachusetts, System Dynamics Society.

Austin, J. 1962. How to Do Things with Words, London, Oxford Univ. Press.

Blakemore, C. and S. Greenfield. 1982. Mindwaves, Cambridge, Basil Blackwell.

Block, N. (Ed.). 1980. Readings in Philosophy of Psychology,2 vols., Cambridge, Harvard Univ. Press.

Brehmer, B. 1989. "Feedback Delays and Control in Complex Dynamic Systems", in Milling, P. and E. Zahn (Eds.) (1989).

Chang, C. and H. Keisler. 1973. Model Theory, Amsterdam, North-Holland.

Forrester, J. 1986. "Lessons from System Dynamics Modelling", 1986 System Dynamics Conference.

Goodman, N. 1973. Fact, Fiction, and Forecast, London, Routledge and Kegan Paul.

Haugeland, J. 1985. Artificial Intelligence. The Very Idea, Cambridge, MIT Press.

Holland, J., K. Holyoak, R. Nisbett and P. Thagard. 1989. Induction. Processes of Inference, Learning, and Discovery, Cambridge, MIT Press.

Johnson-Laird, P. 1983. Mental Models, Cambridge, Cambridge Univ. Press.

Lycan, W. (Ed.). 1990. Mind and Cognition. A Reader, Cambridge, Basil Blackwell.

Meadows, D. 1980. "The unavoidable A Priori", in Randers, J. (Ed.) (1980).

Milling, P. and E. Zahn (Eds.). 1989. Computer-Based Management of Complex Systems, Berlin, Springer-Verlag.

Minsky, M. 1968. "Matter, Mind, and Models", in Blakemore, C. and S. Greenfield (1982).

----- 1975. "A framework for representing knowledge", in Winston, P. (Ed.). 1975. The Psychology of Computer Vision, New York, McGraw- Hill.

Mosterin, J. (1984). Conceptos y teorías en la ciencia,

Madrid, Alianza Editorial.
Randers, J. 1980. "Guidelines for Model Conceptualization", in Randers, J. (Ed.) (1980).
Randers, J. (Ed.). 1980. Elements of the System Dynamics Method, Cambridge, MIT Press.
Rawls, J. 1971. Theory of Justice, Cambridge, Harvard Univ. Press.
Rosenberg, J. and Ch. Travis (Eds.). 1987. Readings in The Philosophy of Language, Englewood, Prentice-Hall.
Rumerlhart, D. 1980. "Schemata: The building blocks of cognition", in Spiro, R., B. Bruce and W. Brewer (Eds.). 1980. Theoretical issues in reading comprehension, Hillsdale, Lawrence Erlbaum.
Schank, R. 1982. Dynamic memory, Cambridge, Cambridge Univ. Press.
Schank, R. and R. Abelson. 1977. Scripts, plans, goals, and understanding: An Inquiry into human knowledge structures, Hillsdale, Lawrence Erlbaum.
Schiffer, S. 1987. Remnants of Meaning, Cambridge, Cambridge Univ. Press.
Searle, J. 1969. Speech Acts: An Essay on the Philosophy of Language, Cambridge Univ. Press.
Sneed, J. 1971. The Logical Structure of Mathematical Physics, Dordrecht, Reidel.
Sosa, E. 1991. Knowledge in Perspective. Selected Essays in Epistemology, Cambridge, Cambridge Univ. Press.
Stegmuller, W. 1979. The structuralist view of theories, New York, SDpringer-Verlag.
Suppes, P. 1960. "A comparison of the meaning and uses of models in mathematics and empirical sciences", Synthese 12.
Tarski, A. 1953. "A General Method in Proofs of Undecidability", in Undecidible Theories, Amsterdam, North-Holland.
Zeigler, B. 1976. Theory of Modelling and Simulation, New York, John Wiley and Sons.
----- 1984a. "System theoretic foundations on modelling and simulation", in Ören, Zeigler and Elzas (Eds.). 1984. Proceedings of the Nato Advanced Study Institute on Simulation and Model-Based Methodologies, Berlin, Springer-Verlag.
----- 1984b. Multifacetted Modelling and Discrete Event Simulation, London, Academic Press.
Vazquez, M. and M. Liz. 1989. "System Formalization and Models Building", Milling, P and E. Zahn (Eds.) (1989).
Vázquez, M., M. Liz and J. Aracil. 1990. "Some Conceptual Problems in the System Dynamics Models Building Process", Andersen, D., G. Richarson and J. Sterman (1990).