Knowledge and reality: some conceptual issues in system dynamics modeling

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This paper provides **a number** of epistemological and methodological reflections on modeling and simulation through system dynamics and the special type of knowledge provided by system dynamics models. Our principal concern will be to analyze the sense in which system dynamics models endeavour to grasp or represent relevant aspects of reality. Two main perspectives have tended to be advanced with regard to this topic: the naive realism linked to philosophies of science, such as those of logical positivism and critical rationalism, and the relativism which emerged from the crisis of said philosophies. We will try to show that some recent epistemological proposals are able to offer a new third way that lies between naive realism and relativism. In particular, the "internal realism" of Hilary Putnam is able to fit many of the features of system dynamics, especially the important role mental models play in it.

System modeling through system dynamics (SD) is a complex scientific and technological activity, for which an epistemological and methodological analysis could suggest some new and interesting perspectives both to practitioners and theorists of SD. In this paper, we will focus on the problem of the sense in which SD models can describe or represent certain relevant aspects of reality. We will tackle this problem in the context of several new developments in the recent philosophy of science.

We want SD models to have the most realistic representational content possible. There is a great difference between purely correlational or statistical models and SD models. SD models are intended to be useful devices for forecasting and control. However, SD models also try to offer explanation and understanding, not only forecasting and control. The problem is that it is very difficult to arrive at formal (logical or mathematical) restrictions which enable us to select and justify the most realistic models from all the possible empirically equivalent SD models that could be built. We know that, formally, the same empirical behavior (the same quantitative data contained in our reference modes or temporal series) can always be generated by many different structures. Furthermore, there is no formal way to decide amongst them or to obtain the ones with the most realistic representational content (from different standpoints, this has been pointed out by Aracil 1986; Putnam 1981; 1983; 1987; 1990; Searle 1985; Zeigler 1976; 1984-and it is very close to some theses of Quine 1969). The only possible strategy to decide among different empirically equivalent SD models appears not to be formal, but closely linked to the way in which real systems are captured by our mental models.

Several reflections have been made with regard to the issue by authors close to SD. Some have suggested that the epistemology of critical rationalism, that is, falsificationism[1] along the lines of that of Popper, could fit SD procedures (Bell and Bell 1980; Bell and Senge 1980). However, critical rationalism has often been criticized because it provides an idealistic view of the scientific enterprise. Critical rationalism firmly believes that it is possible to establish a logic of scientific research, a logic of conjectures and refutations able to assure a progressive approach to an objective truth. There is no doubt that critical rationalism marks a deviation from the inductivist epistemologies of positivism, mainly from the verificationism of the logical positivists, but its insistence on the demands of a single method for all scientific knowledge has the

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same negative effects as those of logical positivism. In the images of science provided by both perspectives, knowledge is understood as the discovery of the structures possessed by reality itself, independent of our entire epistemic contribution. In order to know them, it would be enough to decide to be rational and to follow the general method of science.

However, in order to analyze the sense in which SD models may have an explanatory power and may help us understand complex real systems and manage our actions through them, we need to go back to the real subjects of knowledge. It is necessary to bring into the process of knowledge all the elements overlooked by both positivism and critical rationalism. And, at this point, we must give consideration also to the insights of all the philosophies derived from Kuhn, of the various pragmatisms and holisms, of the structuralist philosophies of science, and of other traditions such as phenomenology, hermeneutics, and so on, which, although falling outside the strict area of the philosophy of science, are nonetheless able to detect very well many of the failures and shortcomings of the so-called "myth of science."

In this vein, other authors close to SD have thought that a relativistic epistemology would offer an adequate framework for the justification of the claims of SD models (Barlas and Carpenter *1990).* By relativism these authors mean some sort of moderate or practical form of relativism, in which the epistemic justification of our models is contextual and relative to the interests and purposes of the participants in the model building process, not an extreme relativism. Extreme relativism can say nothing about justification, whereas moderate relativism can. Extreme relativism is not an alternative epistemology and philosophy of science, but the rejection of all epistemology and all philosophy of science. In extreme relativism, anything can be justified.

It is true that moderate and practical forms of relativism, such as the ones defended by these authors, are perfectly able to make sense of a lot of aspects of SD modeling, for instance the way in which a valid SD model is considered one that proves to be useful with respect to a set of particular interests and purposes. However, the problem with this epistemological point of view is that it cannot say much more. Even though usefulness and success must be important properties of valid SD models, to be useful and to have success with respect to our interests and purposes cannot be the only properties that define the validity of SD models. We want, for our valid SD models, some kind of real explanation and understanding that sometimes goes further than the pre-existent interests and purposes of the participants in the model-building process. Because these interests and purposes change very often through the modeling process, usefulness and success with respect to them cannot be the only relevant properties of valid SD models. Changes of interests and purposes through the modeling process do not fall within the scope of moderate relativism.

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Consequently, we cannot rely on these perspectives (logical positivism, critical rationalism or falsificationism, and relativism) in our attempts to find a solution for the epistemological and methodological demands of real explanation and understanding in SD. Fortunately, there exist nowadays other philosophical perspectives that can help us. In this paper we propose one, namely the "internal realism" of Hilary Putnam (see, for example, Putnam 1981; 1983; 1987; 1990), as a useful philosophical orientation to clarify some of these conceptual problems. This perspective allows us to make sense of how some kinds of realism, explanation and understanding are possible even though (a) there is no privileged single model, or set of models, able to grasp every single aspect of a real system, and (b) there are no formal (logical or mathematical) restrictions that permit us to select and justify the peculiar structure posited by certain models better than all the other alternative structures able to generate the same empirical behavior. The "internal realism" of Putnam would help us to clarify these points by preserving a central place for aspects such as the interactive character of the modeling process and the role which mental models can play as an unavoidable source of knowledge (Meadows 1980).

Knowledge and reality through system dynamics models

SD can also be considered as being a highly sophisticated representational system or conceptual scheme and, in a broad sense, as a "language" that allows us to view and describe reality from a certain point of view. This point of view leads, through a number of particular and interrelated ways of representation, to a final product, which is the SD model. An SD model is a kind of computer model. The tools provided by SD are an adaptation of the mathematical theory of dynamic systems to the representation of some structural and dynamical aspects of reality.

For instance, feedback loops, which structure the behavior of a system, are known to be basic here. When the SD modeler studies a problem, when she begins to build a model, she tries to see how to organize, with the help of these tools, all the knowledge available concerning an aspect of reality, into a SD model. She tries to see in reality, for instance, the feedback loops that help her to structure the model and tries to explain and understand reality through them. This is possible because she knows several archetypes or generic structures which she uses as, let us say, "patterns" or "templates" in order to organize her perception of a given problem. These archetypes or generic structures give a survey of basic structures that appear very often in different problems and that have been more or less typified by SD practitioners and theorists (on this, and in regard to the similarities between SD and the so-called "institutional economics", see Radzicki 1990; see also Senge 1990, especially Appendix 2 entitled "Systems archetypes").

When we build a SD model, three main kinds of knowledge are involved:

1. Structural knowledge: this sometimes comes from the available theoretical knowledge, and is expressed with the help of scientific concepts. However, usually the only source of structural knowledge is the mental models which some subjects, the experts, have about the system to be modeled. In this case, this sort of knowledge is expressed only in intuitive terms and in ordinary language (Forrester 1986).
2. Quantitative knowledge: stated in reference modes, temporal series or, in general, empirical behaviors and in the knowledge concerning the initial conditions in which the real system is placed. In other words, the empirical knowledge that is available with regard to the variations of the relevant magnitudes of the system over time and the particular values of these magnitudes in a given situation.
3. Operational knowledge: the specific SD skills and practical knowledge that the modeller uses when she integrates the other two kinds of knowledge, obtaining a special formal representation, the SD model. The SD model simulates the dynamic behavior of the modeled system and assumes that it contains a certain structure. It is intended that the SD model will be able to guide our policy actions through the real system.

It is essential to have these three kinds of knowledge coherently included in our SD models. While empirical behaviors give the quantitative data and anchor in reality the quantitative results and predictions of SD models, mental models give information which is not so much quantitative as structural. Mental models are sometimes supplemented with particular applications of available theories but, if none is available, they constitute the only source of structural knowledge concerning the systems being modelled. In any case, and even with the help of theories, mental models are fundamental both to postulate a certain structure and to steer our action with the help of SD models. From this point of view, mental models are a basic and indispensable source of knowledge in the process of building SD models. SD models must be guided by mental models. In SD, mental models are understood as the basis, and the first step, of the modeling process (Meadows 1980).

Lastly, SD operational knowledge gives the basis with which to articulate all the information, ideas and hypotheses. The end product of the modeling is an abstract or formal representation, a model in SD format, which, with the help of very special concrete objects, computers, enables us to integrate, broaden and make clear and operative both the previous more or less intuitive knowledge provided by mental models and the quantitative knowledge obtainable from reality.

We work from the premise that mental models are some sort of psychological construction with an intended representational content. Mental models lead to certain descriptions of reality that are usually expressed by a set of sentences in ordinary language, describing both the interactions among the elements within the system and their external influences. These sentences describe the qualitative way in which a change in one magnitude leads to variations in another. As we have said, this information sometimes comes from well known and sound theories, but in SD it is very usual for it to come only from the individual viewpoints of the subjects involved, as participants or experts, in the systems being analyzed.

At this point, it would be convenient to point out three important attributes of mental models:

1. Mental models are not fixed; they change with experience, action and discussion, and also through the SD model-building process.
2. Mental models are not simple; they contain rich and relevant information about the basic components and structural relationships of the systems in which subjects are involved. 3. The structural information that mental models provide about certain systems, that, like socio-economic ones, are the result of human actions guided by these same mental models, is usually reliable.

In other words, mental models can be said to be strongly interactive and to have a very rich and relevant representational content regarding the structure of the systems; moreover, in some cases, this structural information is highly reliable.

SD models are rational structures that generate a formal behavior which must fit the empirical behavior of the system being modeled. For a model to be accepted as valid, in the first place, it is necessary that the hypotheses used to build the model be compatible with available scientific or heuristic knowledge. Secondly, these hypotheses must be able to be captured adequately with the representational tools of SD language, and all this information must be processed properly to obtain conclusions that will fit the empirical behavior. So far, we have some sort of empirical adequacy, able to offer forecasting and control. However, the validation of our SD models requires something further. It also has to explain and understand the structures that really work in the systems. SD models must provide explanation and understanding. Only in this way is it possible to clarify and render operative the previous mental models upon which they are based.

An SD model is the final result of the progressive refinement and formalization of a mental model, and this refinement and formalization is not merely quantitative. One important target is to obtain a formal model that can generate empirical behaviors. However, it is also very important to obtain a formal model able to explain and render comprehensible these behaviors. This formal model must allow us to understand and explain how the behavior is generated from the supposed structures. Thus, the role of our SD models is not only to generate a certain behavior, but also, to a certain extent, to explain and understand how this behavior is generated. And this directly involves making connection with the way in which mental models represent real systems. Perhaps the same quantitative results could be obtained by means of correlational or statistical strategies. There are other possible modeling techniques that, although totally unlike our use of mental models, can achieve more or less the same forecasting and control power, but, for SD models to provide explanation and understanding, and not merely forecasting and control, they must link up with, and be in constant touch with, mental models. This is one of the most distinctive and important characteristics of SD modelling.

The problem encountered here is that it is impossible to find either empirical or formal (logical or mathematical) restrictions that enable us to select a single SD model, or set of SD models, as the one(s) having the intended most realistic representational content. Sometimes, we have empirically equivalent SD models, that is, several alternative SD models able to reproduce the same empirical behaviors. On other occasions, we have to choose, for example, between a large and a small SD model. These problems undermine considerably the claim that our SD models grasp or represent relevant aspects of real systems, and that their epistemological justification can assure these realistic claims. What is meant when it is said that a given SD model represents an aspect of reality? What is the scope of our claim that we represent faithfully, through our SD models, several aspects of real systems? What does the SD model capture from reality, or, put another way, what does it reproduce from reality?

The most important challenge in this respect in current philosophy of science is the search for a third way, between the naive realism, such as that of the old philosophy of science, including here some of the views of Popper, and the relativist trends of recent philosophy. Naive realism is very well represented in the context of SD by analyses such as those of Bell and Senge (Bell and Bell 1980; Bell and Senge 1980). Relativism is also present in this context and some moderate or practical versions have been defended, for instance, by Barlas and Carpenter (1990). However, as we will attempt to show in the next sections, a third way is possible in philosophy of science in general and, in particular, in epistemological and methodological reflections on SD modeling.

The realistic claims of system dynamics models

SD models must have the most realistic content possible. Only in this way is it possible to have explanations and understanding, and not just forecasting and control. However, there is no pure appeal to experience that could make it possible to determine whether or not we succeed in being in adequate touch with reality. Neither are there any kind of formal (i.e. logical or mathematical) restrictions which are able to select and justify a single model from the various alternative models, each positing a different structure, that can generate the same behavior. To look for some sort of direct confrontation with reality or for some sort of ultimate formal restrictions is merely to repeat an old-fashioned epistemological project, one which presupposes that our knowledge requires some sort of absolute foundation. But no such foundation exists, either in experience or in the formal realm of mathematics or logic.

We have emphasized very negative results thus far. However, in spite of these negative results, we must not rely on relativism and abandon our aim of clarifying the elements involved in the justification of our models. Indeed, seeking clarification of these elements is the only way to improve our own justificatory strategies. Because of this, extreme relativism must be discarded. Extreme relativism is no more than absolute scepticism with regard to justification. If anything can be justified, then nothing is. Extreme relativism fails to impose the minimal order on our beliefs that is necessary for justification. Moreover, it would not be enough to say, either, as moderate relativism does, that these justificatory strategies are always relative to our interests, goals, explanatory purposes, and so on. Of course they are. However, what we want to know is when, in such a relative and dependent situation, we would be justified, and why. Moderate relativism is a much too moderate epistemological point of view.

Thus, the problem remains. How can we be confident in identifying a structure as the generator of the behavior of the real system? Or, put another way, where do the restrictions that allow us to distinguish the most realistic models come from?

Explaining and understanding the behavior of a system requires the identification of some mechanism or structure that, from the standpoint that guides the SD model-building process, may be considered as the one which brings about the behavior. When this does not happen, we can reject the simulations of the systems, and the SD models, as being non-explanatory and as not providing enough understanding of the situation. This is so because forecasting and control are not the only goals of SD modeling. Beyond forecasting and control, SD model builders and users want to achieve a deeper knowledge of the real systems their SD models are about.

It is true that, if we have access to theories concerning the system we are modeling, it is easier to select the structures that may be considered to be responsible for the behavior in question. In this case, theories guide the SD model-building process, suggesting which ones might really be the relevant causal elements. In SD modeling, however, precise and established theoretical knowledge, of which our models are an application, is usually absent. Moreover, we tend to rely most of the time on the help of SD to model complex socio-economic systems because we do not have here easily applicable theories. And in relation to these systems, the problem of being more or less committed to the structures posited by our models is decisive for their utility and effectiveness.

This last remark places us on the right track with respect to our problem. If SD models have to interact, as they do, so strongly with mental models in order to be useful and effective in decision-making with regard to what policy actions to adopt, then mental models can also interact with SD models in order to identify the sort of structures that, from the point of view that guides the modeling process, must be assumed to be the ones responsible for the behaviors of the real systems. We have also said (earlier) that mental models offer rich and relevant information about the structural elements and relationships of certain special systems, such as socio-economic ones, and that, even if mental models on their own cannot obtain all the dynamic consequences of the structural information, this information is, in many cases, highly reliable.

All this entails two important things with respect to SD models, or at least with respect to SD models that are built without the direct help of relevant theories, and that are designed to steer our policy actions through the systems modelled, as is usually the case of SD models concerning complex socio-economic systems:

1. SD models must have a realistic character from the point of view of the mental models of the users of these SD models.
2. The restrictions that can enable the most realistic SD models to be distinguished may, in some cases, come from the structural information provided by the mental models of the experts on which the SD models are based.

In which cases, and why, could mental models identify and distinguish these most realistic SD models? The answer to this question is crucial. Mental models can do so when the actions of the subjects that have these mental models are among the actual causes that produce the structure of the concrete systems around which the SD models are built.

The structures of many systems are caused intentionally by the beliefs, desires, goals, etc. of some agents. These systems are an intentional effect of the mental models of the agents involved in their production. Socio-economic systems are paradigmatic examples of this. The structure of such systems mirrors the intended structure that is present in the mental models of the subjects responsible for their existence. Certainly, most of the time the dynamics of such systems, their behavior, is not the one which is expected or desired. However, from the point of view of the agents, their structure, their real structure, is often very clear. The agents themselves impose these structures on reality creating systems that are simply not found in nature. (On this point see Senge (1990), particularly Part I entitled "How our actions create our reality . . . and how we can change it.").

To recapitulate, SD models are not only devices designed to achieve forecasting and control. If the internal structure of a SD model is completely different from the way users of the SD model think the real system is structured, the SD model will be of no use in helping to understand and explain the system and will not be a good guide for managing action. Thus, SD models must possess some sort of realistic character from the point of view of the users of the SD models. And the way the most realistic SD models can be selected among alternative SD models featuring different structures, even though they are empirically equivalent with respect to the behavior involved, is again through certain mental models, those of the experts in the systems being modeled. SD models must have a realistic character from the point of view both of the users of the SD models and of the experts in the real systems that are modeled.

Sometimes, users and experts are one and the same. That is, the users of a SD model can be, at the same time, those from whom SD modelers have obtained the relevant structural knowledge. Furthermore, sometimes users, experts and modellers can be one and the same. In this case, SD "language" is incorporated into our cognitive skills, helping us to make clear and operative our own mental models. At other times, users, experts and modelers are different people, which is the more common case with regard to complex socio-economic systems that involve actions and decisions of very different people. Here, the relationships of the users, experts and modelers are more indirect and intricate. Nevertheless, points 1 and 2 mentioned above continue to be very important, in order to assure the usefulness and epistemological justification of SD models.

In SD, mental models are always a very important part of the knowledge of the real "mechanisms" of systems. Sometimes, they are the only knowledge we have about them. When no theories are available, mental models must play a crucial role in order to choose the structures able to generate some behaviors. These mental models offer the minimal conditions for a realistic adequacy of the structures of our SD models.

The epistemological perspective of Putnam's internal realism

Among the perspectives in today's philosophy of science and epistemology that study the general problem of realism, there is one that could be of great use here to make clear the way in which mental models help to select the structures that, from the SD point of view, must be assumed as working in real systems. We are referring to the "internal realism" (IR) of Hilary Putnam (see, mainly, Putnam 1981; 1983; 1987; 1990).

From the perspective of IR, sometimes also called by Putnam "pragmatic realism", or simply "internalism", to think that there must exist a unique adequate description, theory or model for each real system, or for reality as a whole, waiting simply to be discovered, is a myth. Putnam maintains that it makes no sense to ask what really exists outside our conceptual schemes. There is no point in claiming that our descriptions, theories and models can display reality to us as it itself actually is, independently of any conceptual framework. It makes no sense because that independence would mean merely knowing reality, but without doing so through our descriptions, theories and models. And that is simply impossible.

There may always exist an indefinite pluralism of alternative conceptual schemes, which we do not know, previous to adopting some individual point of view, whether or not they finally converge. The existence of several conceptual schemes that structure experience in different ways is always a possibility. Even an ideal epistemic situation of empirical and conceptual control, including here all the relevant observations and empirical tests, all the relevant logical and mathematical analysis, and so on, would not be able to eliminate that pluralism without the intervention of decisions and choices that are reasonable from some point of view.

In spite of these problems, all of us are more realistic with respect to some things than to others. This is a fact regarding how we want to know and act. The success of our predictions and actions may not be all that we try to obtain from our relationships with reality. Moreover, it could not be all because, at least, we would need to distinguish between real success, in our prediction and action, and the mere appearance of success. And at this point, we would need to adopt realistic compromises. A simple operationalist or instrumentalist view is really untenable.

An adequate conception of realism must be compatible with these two claims. On the one hand, with the fact that all our knowledge is developed through our descriptions, theories, models, criteria of relevance and interests, and, on the other hand, with the fact that we often adopt very realistic commitments with certain objects and properties. Putnam states that any assertion about real existence is relative to a general framework, to a conceptual scheme. However, he maintains at the same time that these conceptual schemes do not lead us to any kind of relativism. It makes sense only to adopt realistic compromises from within our conceptual schemes. However, from within our conceptual schemes, relying on our descriptions, theories, models, and so on, decisions about what is real or not are not a business of mere choice or convention; nor do they depend merely on our interests and purposes. Although our conceptual schemes may be diverse, they may have objective criteria of truth within them. There are no absolute criteria, but this does not mean that there are no criteria.

It is important to see that realism in the sense of IR is not a substitute for another, difficult but nonetheless possible, stronger kind of realism. If we accept the historical development of recent philosophy of science, the sense in which IR is realistic may be the only sense in which one can be realistic at all. It is also important to consider that, even if we assume the pluralism of our conceptual schemes, nothing in IR precludes the convergence of several descriptions, theories or models. It is true that we cannot know in advance whether, in general, two or more alternative conceptual schemes converge or not, prior to our attempts to achieve such convergence. However, we could achieve that convergence by elaborating other descriptions, theories and models. Incommensurability is only a question of fact. Relativism usually understands the phenomenon of incommensurability as an insurmountable problem. This is very often shared by extreme relativism and by moderate forms of relativism. However, it must be made clear that IR is not a variety of relativism.

What Putnam's IR does is to discard the so called "God's eye" point of view in science and philosophy. The "God's eye" point of view would offer total, objective, perfect and definitive knowledge. This is what Putnam calls "metaphysical realism" (MR), or "externalism." From the point of view of MR, reality would have (in Putnam's words) a ready-made and fixed structure that our descriptions, theories and models ought to grasp. Moreover, there would exist only one true description, theory or model for the whole of reality and for each of its parts. Truth would consist of some sort of relation of correspondence between the structure of reality and the structure posited by our descriptions, theories and models.

MR was the general epistemology of almost all the philosophies of science in the first half of this century. However, it never managed to explain many things. The relation of correspondence between reality and our concepts remains a total mystery. Neither can it make sense of the existence of structurally different but empirically equivalent descriptions, theories and models. In addition, the ready-made structure that MR supposes in the world contradicts the intuition that perhaps the dividing line between the objective and the subjective is not as clear-cut as we sometimes imagined.

However, MR is not only the epistemology of philosophies of science such as those of logical positivism, falsificationism and so on. Part of this MR also belongs to the image of reality that sometimes impregnates certain forms of relativism. According to Putnam, relativism of these kinds is also MR when it suggests that reality can be seen as something with a ready-made and fixed structure, but one which necessarily falls outside the scope of our best attempts to obtain knowledge of it. So understood, relativism would also demand a "God's eye" point of view. It would be only a pessimistic MR.

Let us go back for a moment to the problem of the existence of a world with a ready-made and fixed structure. This is the main point that justifies all the other claims of MR, but, what does it mean? Let us think, for instance, of all our institutions or all our socio-economic systems, all the systems that are the result of human conceptions, decisions and actions. What are their structures? Are they ready-made and fixed, independently of our conceptions, decisions and actions? Surely not. We impose on reality certain structures which give rise to those systems. And these same structures and their dynamical properties are precisely what many times we aim to know better, to explain and understand, through our descriptions, theories and models.

At this point there is a strong temptation to say that IR might be a good perspective in relation to artificial systems such as those mentioned just now, but not in relation to natural systems like those studied in physics. It would suffice for us to adopt IR only in relation to the first kind of systems. After all, the analysis of that special type of systems is one of the main concerns of SD. However, for Putnam that would be a typical MR temptation. If there is no approach to reality, even no observation, that is not loaded with our conceptual schemes, if there is no access to reality which is independent of our conceptions, decisions and actions, then what we always achieve and all that we can achieve is a combination of something natural and something artificial. A combination or mixture in which it is impossible to separate completely the component elements. As Putnam says in one of his last books (Putnam 1987), "The Trail of the Human Serpent is Over All."

The combination of the natural and the artificial that we find in all of reality makes it impossible to distinguish between the world of science and the common-sense world. These two worlds overlap in many ways. And this is the reason for the collapse of all kinds of reductionist claims. In particular, it does not make sense to think that it would be possible, even in principle, to reduce to the language of physics every significant statement. Physics can no longer be the only privileged sort of knowledge that tells us how reality itself is. (With respect to the problems of the distinction between the natural and the artificial in all our relationships with reality, see the interesting and now classic work of Simon (1973)).

What consequences for SD can we draw from all this? We have seen that in IR there is no point in asking what really exists beyond our conceptual schemes, and that there are no privileged structures in reality waiting to be discovered by us independent of our epistemic contribution. From this point of view, we could say perfectly well that SD is a clear example of how some epistemic elements, the mental models of the experts involved in real systems and the mental models of the users of SD models, can select the structures that must be assumed as working in the real systems.

SD operational knowledge offers a survey of archetypes of generic structures (feedback loops and so on) and ways to obtain dynamic behaviors from these structures. As we said above, in a wide sense SD could be considered as a "language". With the help of this "language", we see and describe reality. This "language" guides our perception of the problems and our actions, rewriting our mental models. SD offers a new way to organize experience, new tools to help us know and act. However, mental models are necessary in order to link with reality the archetypes or generic structures that are the basic representational elements of SD "language." Mental models provide realistic content to the structures posited by SD models.

The mental models of experts impose these structures on reality and are part of the structuring cause of the systems in which the experts are involved. Moreover, these same mental models interact with SD models in the search for forecasting, control, and some sort of deeper explanation and understanding of the dynamical properties of the real systems. In this way, the mental models of the experts become the mental models of the users of SD models (as we have said, sometimes they are one and the same, but not always). The selection of the SD models with the most realistic content must be made by experts and users and has a crucial justification in relation to the structural dependence and sensibility that some real systems have on the human actions developed in them.

SD models are typically constructed upon the intuitive and presystematic knowledge of people who are particularly related to the systems being modeled. SD models may be explanatory and allow us to know these systems better, not just to forecast and to control them. However, these explanations and this increase in knowledge are always internal to some conceptual framework or frameworks, to the mental models of real and concrete persons clarified and improved through the operational knowledge provided by SD. From the point of view of the externalist philosophies of science (with "God's eye") such as those of logical positivism, Popperian falsificationism, and so on, these explanations and understanding are neither completely explanatory nor do they amount to genuine knowledge. From Putnam's internalist view, however, they may be. The reason is that all knowledge and every explanation must be internal to some conceptual scheme. The explanation and understanding provided by SD models could be adequate from within the very conceptual scheme of SD.

With respect to complex socio-economic systems, these conceptual schemes involve part of an ordinary common-sense framework, the ordinary common sense applied to the actions undertaken in a socio-economic environment. Putnam thinks that it is not possible to separate the common-sense world and the world of science. In the case in which the most important things that need to be known are actions undertaken, possible decisions, etc., as is the case of complex socio-economic systems modeled through SD, this thesis is revealing. There is no other way of access to the structures of these systems other than the intuitive representations held by the subjects involved in them, because, in the end, their decision and actions, guided by their mental models, perhaps in interaction with SD models, are among the causes of those structures (see, again, Senge 1990, Part I).

The questions of pluralism and convergence, as analyzed by Putnam, are also very important to us. Sometimes several SD models may be in an extreme position of incommensurability. That is, they may be empirical equivalents and have the same realistic plausibility from the point of view of mental models. Certainly, pluralism is not unusual in SD. However, this pluralism must be considered only as a contingent fact and not as something necessary. Convergence of different SD models can be achieved in SD modeling thanks to the strong interactive character of mental models. It could even be achieved through reasonable decisions and choices. SD modeling is a continuous process of revision and adjustment. However, it is one thing that convergence can be achieved in this way and another very different thing that we do actually achieve it. Convergence is also a contingent fact that cannot be known in advance.

From the epistemological perspective of IR, we could avoid the classic concerns about the ideal aim, pluralistic or convergent, of our human knowledge. And we could also avoid the classic references to aspects such as the reduction of SD causal relations to other, causal relations assumed to be more basic. This last point is very promising with respect to the methodological debates among (mainly neoclassical) economists and SD practitioners and theorists. If the epistemological perspective of IR is adequate, no kind of fundamental micro-economic theory would be needed to explain and give justification to the macro-causal relations posited in SD models of socioeconomic systems (on this, see Radzicki 1990). Reduction is a kind of causal explanation, but it cannot be the only kind of sound causal explanation outside physics. Outside physics there may be non-reductive but very sound causal explanations. And reduction, like pluralism and convergence, is only a contingent matter.

We can find in Putnam's IR the rejection of both the MR of some philosophies of science and the pessimistic versions of this MR that one can sometimes find in relativism. IR is in fact a third way between the naive realism linked to the old positivist philosophies of science, such as those held by logical positivism, by falsificationism, etc., and the relativism linked to the crisis in such philosophies. The possibility of some kind of moderate relativism that does not entail absolute relativism remains an open question. But, in any case, if this moderate relativism, in the context of SD, only claims that usefulness and success with respect to our interests and purposes must be important properties of valid SD models, it fails to provide a satisfactory account of how these interests and purposes themselves can change in the SD modeling process.

Conclusions

In this paper, we have tried to show that, beyond the demanding images of science provided by, among others, logical positivism and Popperian falsificationism, and beyond the conformist relativism inspired in philosophers such as Kuhn, current philosophy of science offers many new insights from which we can achieve a better understanding of SD modeling and simulation. In particular, Putnam's IR offers a third important way between naive realism and relativism. IR can help us tackle some of the problems we usually meet when modeling with SD, especially the problem of how the justification of SD models can guarantee some realistic representational contents and make possible some kind of explanation and understanding, in spite of the plurality of alternative SD models which is often encountered.

For IR, it does not make much sense to suppose a passive reality, one which is ready-made and structured independently for our knowledge and actions, from which our models can at best be copies. The same is true of SD, where knowledge from mental models is such an important part of the building and justification of the final SD models. Neither is there a unique version, a unique and total model, able to grasp every single aspect of a real system. However, although the question of which structures really produce a certain behavior makes no sense from outside our conceptual schemes, from within them it is a decisive question and not a matter of mere choice, convention or something answerable from a simple relativism.

In short, from the IR of Putnam, SD can be seen as a powerful conceptual scheme able to articulate our experience in new and promising ways. Putnam's perspective enables us to clarify the strong interactive character of the modeling process, its realistic claims and its search for an explanation and understanding, even though there are no absolute or uniquely valid models. It also enables us to clarify the contribution of modelers, of experts, of the users of models, and of reality itself to the model building process.

Note

1. A useful definition of "falsificationism" appears in the *Dictionary of Jargon* (Green, J. 1987, London: Routledge and Kegan Paul): "(Sociology) a doctrine which claims that scientific advance can only come through testing and falsifying hypotheses, which are then replaced by new hypotheses to be tested and falsified in their turn; one can only falsify, never ultimate verify." A fully definition and discussion of the term and of Popper's formulation of the principle appears in *The Concise Oxford Dictionary of Sociology* (Marshall, G. ed. 1994. Oxford University Press).

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