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Not Just Underlying Structures: Towards a Semiotic Approach to Scientific Representation and Modeling

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1. Introduction

The question of representation has started to interest philosophers of science only rather recently. Before the end of 1980's, the term representation was hardly used in the general philosophy of science and when it was, it was neither thematised nor questioned. This situation started to change largely due to the renewed interest in modeling. Unlike with propositions and sentences, such terms as "true" and "false" did not seem to be apt in dealing with the relationship between models and their real-world target systems; and the question then became how these models were linked to the world. "Representation" was considered to be more appropriate term than "truth" in capturing this relationship.

Philosophers of science have indeed been nearly unanimous in saying that models have to represent in order to give us knowledge. Yet, their preferred accounts of representation have differed widely from each other and no consensus as to how representation should be approached has emerged. Interestingly, however, several recent writers on the topic have stressed, in one way or another, that representation is a pragmatic notion involving either the "users" or "interpretation". This means a definite shift in the discussion of scientific representation from dyadic accounts of representation toward triadic ones. In the following I will trace the turn from the dyadic structuralist accounts of representation to triadic pragmatist accounts, discussing the reasons for this development and how it enables a semiotic approach to be taken to scientific representation.

2. Dyadic accounts of scientific representation

Up until recently the reigning conception of scientific representation has been the semantic, or alternatively the structuralist, account of models. The semantic account approaches representation as a dyadic relation between two things, the real system and its abstract and theoretical depiction. According to the semantic conception, models are taken as structures whose relationship with their target systems is analyzed mostly in terms of an isomorphism: a given structure represents its target system if both are structurally isomorphic to each other (see da Costa & French, 2000; French & Ladyman, 1999). By isomorphism it is referred to a kind of mapping that can be established between the two that preserves the relations among elements. Consequently, the representational power of a structure derives from its being isomorphic with respect to some real system or a part of it. One of the advantages of invoking isomorphism seems to be that it can be given a precise formal formulation, which cannot be given for instance to similarity, which is another candidate offered for the analysis of a representational relationship (see Giere, 1988). Also other morphisms, such as partial isomorphism and homomorphism, are occasionally proposed as candidates for analyzing the representational relationship (da Costa & French, 2003; Bartels, 2006). The basic idea behind all approaches relying on a morphism of some kind is that the morphism between the two structures, the model and its target system, guarantees the representational relationship between the two. Consequently, even though the proponents of the semantic approach do not contest the importance of pragmatic factors when it comes to representation in scientific practice, they nevertheless claim that the underlying structures of both the model and its target ground the representational relationship.

The above-mentioned theoretical attractiveness of isomorphism – or any other morphism for that matter – vanishes once we realize that the parts of the real world we aim to represent are not "structures" in any obvious way, at least not in the sense required by the semantic theory. It is perhaps possible to ascribe a structure to some part of the real world, but then it is already modeled (or represented) somehow. This has, of course, been noticed by the proponents of the semantic theory; Patrick Suppes has for instance invoked "models of data" (1962). Thus the isomorphism required by the semantic account concerns actually the relationship between a theoretical model and an empirical model.

Even if we disregard the fact that the world does not present itself to us in ready-made structures, isomorphism does not seem to provide any adequate account of representation. Isomorphism denotes a symmetric relation whereas representation does not: we want a model to represent its target system but not vice versa.[1] Moreover, the isomorphism account does not accept false representations as representations.[2] The idea that representation is (at least partly) either an accurate depiction of its object or then it is not a representation at all does not fit our actual representational practices. Both problems appear to be solved once the pragmatic aspects of representation are taken into account. The users' intentions create the directionality needed to establish a representational relationship; something is being used and/or interpreted as a model of something else, which makes the representational relation triadic, involving human agency. This also introduces indeterminateness into representational relationships: human beings as representers are fallible.

3. Pragmatic approaches and their implications

The critical importance of the use to which representations are put has recently been expressed in various ways by Ronald Giere (2004, 2010); Mauricio Suárez (2004, 2010) and Daniela Bailer-Jones (2003). Of these pragmatic accounts of scientific representation, the one advanced by Bailer-Jones is possibly the most traditional. She discusses representation in terms of propositions entailed by models. By entailment Bailer-Jones does not mean logical entailment, for models "use a whole range of different means of expression, such as texts, diagrams, and mathematical equations", and thus some of the content of a model may be expressed in non-propositional forms. As a result the number of the propositions entailed by a model cannot be conclusively determined. Moreover, models typically entail propositions that are known to be false. This leads Bailer-Jones to consider the functions of models, since models containing false propositions can be accepted for some "higher purpose". Because "a model is intended to meet

[1] This also applies to the similarity account of representation. For thorough studies on the formal and other properties that we might expect an acceptable concept of representation to satisfy, see Suárez (2003) and Frigg (2003).

[2] See however Bartels (2006), who argues that the different criticisms of isomorphism, including the impossibility of misrepresentation, do not apply to the version of homomorphism that he is putting forth as an analysis of the representational relationship.

a certain function... the attempt to meet the function overrides the striving for the model's proximity to truth" (2003, p. 70).

The proposal to speak of representation in terms of propositions entailed by models seems somewhat paradoxical, for as long as philosophy of science operated predominantly on the basis of propositions (derived from theories and models) and their fit with the data (via the procedure of testing), the question of representation did not arise. This question becomes acute once we grant that much scientific reasoning operates on other representational means than (propositional) language. The point of using various representational means arises out of their different affordances in conveying diverse kinds of information, much of which cannot be readily, if at all, propositionally presented. Consider for example how much information a picture or a diagram can convey to us at a glance. In Peircean terms, Bailer-Jones fails to pay enough attention to the expressive and inferential power of the *iconicity* of signs in striving to reduce their content to symbolical form. Besides, as Bailer-Jones leaves the notion of "entailing" unexplained, one is left wondering why it is that models "entail" some propositions and not others. This seems to have something to do with the representational power of models, which this account of representation has actually left untouched.

Ronald Giere (2004), for his part, is explicit in stating what the representational power ultimately hinges on. Though his views on models and representation have changed substantially since the semantic conception propounded in *Explaining Science* (Giere, 1988), he still claims that representation is based on a similarity of some kind. Giere notes that even though no objective measure of similarity can be given, "it is the existence of the specified similarities that makes possible the use of the model to represent the real system" (2004, p. 748). No general analysis of similarity is needed (or can be given) to explain scientific representation because of the irreducibly pragmatic nature of scientific representation. Consequently, instead of concentrating on the two-place relation between a representational vehicle and its target system, Giere proposes that representation can be thought of as having at least four places with roughly the following form:

S uses M to represent W for purpose P.

In the above form, S can be anything from an individual scientist to a scientific community. M is a model, and W stands for an "aspect of the real world, a (kind of) thing or event". More informally, the message of the form can be expressed as: "Scientists use models to represent aspects of the world for various purposes" (2004, p. 747).

In line with Giere, Mauricio Suárez criticizes dyadic conceptions of representation because of their attempt to "reduce the essentially intentional judgments of representation-users to facts about the source and target objects or systems and their properties" (2004, p. 768). As opposed to Giere, however, Suárez does not want to "naturalize representation". This means that he resists saying anything substantive about the supposed basis on which the representational power of representative vehicles rests, i.e. whether it rests for instance on isomorphism, similarity or denotation. According to Suárez such accounts of representation err in trying to "seek for some deeper constituent relation between the source and the target", which could then explain as a by-product why, *firstly*, the source is capable of leading a competent user to a consideration of a target and *secondly*, why scientific representation is able to sustain "surrogate reasoning". Instead, Suárez builds his inferential account of representation directly on these by-products. Consequently, Suárez calls his account of representation "deflationary" – or "minimalist": no deeper features are sought, instead one settles with the surface features.

The formulation Suárez (2004, p. 773) gives to the inferential conception of representation is the following:

> A represents B only if (i) the representational force of A points towards B, and (ii) A allows competent and informed agents to draw specific inferences regarding B.

This formulation presupposes the activity of competent and informed agents. The "representational force", according to Suárez, is "the capacity of the source to lead a competent and informed user to a consideration of the target". This "relational and contextual property of the source" is fixed and maintained in part by the intended representational uses of the source by the agents (2004, p. 768). Part 2 of the formulation contributes to the objectivity that is required of scientific representation. Suárez claims that in comparison to Part 1, Part 2 depends in no way on an agent's existence or activity. Instead "it requires A to have the internal structure that allows informed agents to correctly draw inferences about B" (2004, p. 774). Thus even though Suárez does not want to specify what kind of a relation there is between the source and the target, it nevertheless has to be grounded on the construction of the representative vehicle somehow.

Of all the pragmatists of scientific representation, Suárez challenges most explicitly the idea that representation could be accounted for by reverting only to the properties of the model and its target system. Consequently, Suárez can be interepreted to claim, in line with Peircean semiotics, that representation as a sign relation is genuinely a triadic notion (EP 2:272–3). Thus, there is no single determinable relationship between a certain model and its target system. This has important consequences for how we understand scientific representation. Firstly, as representation cannot be given a general substantive analysis, in each case of representation the extent to which human representers make use of the iconic, indexical or symbolic qualities of the representamen, i.e. the model, is open to further study. This in turn means, secondly, that the focus is shifted from the features of the model and the target system to the interpretive activity of the scientists, that is, to the process of semiosis. Indeed, in the recent discussion on models, the earlier emphasis on representation has been replaced by the attempts to approach modeling from a mediative and productive perspective. A central move taken by that approach is to consider models as independent entities that can be used to gain knowledge in a multitude of ways.

4. Models as epistemic tools

The idea of models as independent entities has been expressed by several recent authors in various ways. Morrison (1999) and Morrison and Morgan (1999) have considered models as *mediators*, which through their construction are partially independent from theory and data. This is because besides being comprised of both theory and data, models typically also involve "additional 'outside' elements" (1999, p. 11). Boumans (1999) for his part disentangles models from the theory-data framework altogether. In his study on business-cycle models he shows from how many different "ingredients" a model can be constructed, such as analogies, metaphors, theoretical notions, mathematical concepts, mathematical techniques, stylised facts, empirical data and finally relevant policy views. From a somewhat different perspective, Weisberg (2007) and Godfrey-Smith (2006) have also come to the conclusion that models should be treated as independent entities. For them independence means independence from a certain real target system. Thus instead of conceiving independence in terms of the relationship of models to the theory and data, they release models from representing any definite real target system. According to Weisberg and Godfrey-Smith, modeling can be viewed as a specific theoretical practice of its own that can be characterized through the procedures of indirect representation and analysis that modelers use to study the real world phenomena. With indirect representation they refer to the way modelers, instead of striving to represent some real target systems directly rather construct simple, ideal model systems to which only a few properties are attributed. As Godfrey-Smith has aptly put it, modeling can be characterized by the "deliberate detour through merely hypothetical systems" it makes use of (2006, p. 734).

Considering models as independent entities urges one to address them as concrete constructed objects whose cognitive value derives largely from our *interaction* with them (Knuuttila & Merz, 2009). From this perspective, models give us knowledge not because they happen to represent their target systems more or less accurately but because they are purposefully constructed so as to allow inferences of various kinds. Apart from licensing inferences, models are also used for other tasks such as prediction, measuring, devising experiments etc. Consequently, models can be considered as multifunctional *epistemic tools* (Knuuttila, 2005; Knuuttila & Vouti-lainen 2003). The importance of our interaction with models is recognized by Morrison and Morgan (1999), who stress that we learn from models by constructing and manipulating them. However, it seems that they leave this important idea somewhat underdeveloped. Namely, if our aim is to understand how models enable us to learn from the processes of constructing and manipulating them, it is not sufficient that they are considered as autonomous: they also need to be concrete in the sense that they must have a tangible dimension that can be worked upon. This concreteness is provided by the material embodiment of a model: the concrete representational means through which a model is achieved gives it the spatial and temporal cohesion that enables its manipulability. This also applies to so-called abstract models: when working with them we typically construct and manipulate external representational means such as diagrams or equations. Thus even abstract entities need to have a material dimension to give us knowledge. Herein lies also the rationale for comparing models to experiments: in devising models we construct self-contained artificial systems through which we can make our theoretical conjectures conceivable and workable.

The mere structure supposed to underlie any model – on which the semantic conception of representation focuses – does not take us too far. The very variation of the different kinds of models used: scale models, pictures, diagrams, different symbolic formulas and mathematical formalisms, suggests that the material and semiotic dimension of models and the diverse representational means they make use of, are crucial for their epistemic functioning. The representational means used have different characteristic limitations and affordances; one can express different kinds of content with symbols than with iconic signs such as pictures and diagrams, for example. From this perspective the use of diverse external representational means provides external scaffolding for our cognition, which also partly explains what is commonly ascribed as the heuristic value of modeling. It is already a cognitive achievement to be able to express any hypothetical mechanism, structure or phenomenon of interest in terms of some representational means, including assumptions concerning them that are often translated in a conventional mathematical form. Such articulation enables further theoretical inferences as well as new experimental set-ups, but it also imposes its own limitations on what can be done with a certain model.

Another aspect of the scaffolding provided by models is related to the way they help us to conceive the objects of our interest clearly and to proceed in a more systematic manner. Models are typically constructed in such a way that they constrain the problem at hand – which happens typically by way of idealizations and abstractions – thereby rendering the situation more intelligible and workable. As the real world is just too complex to study as such, models simplify or modify the problems scientists deal with. Thus, modelers typically proceed by turning the constraints (e.g., the specific model assumptions) built into the model into affordances; one devises the model in such a way that one can gain understanding and draw inferences from using or "manipulating" it. Yet the seeming simplicity of models disguises the heterogeneity of elements they incorporate, such as familiar mathematical templates, already established theoretical entities, relevant scientific knowledge, certain generally accepted solution concepts, the intended uses of the model, the epistemological criteria that are supposed to apply to it and so forth. All these things that are built into a model provide it also certain original built-in justification (Boumans, 1999). These aspects of models explain, on the one hand, how they allow for *particular* kinds of solutions and inferences, and on the other hand, how they can also lead to unexpected findings, breeding new concepts, problems, and even novel lines of research.

5. Conclusion

In his later work, Peirce's earlier focus on representation became replaced by mediation and production of interpretants.[3] Interestingly, the same has happened in the discussion on models and representation where a more

[3] See e.g. Bergman (2004, Ch. 4).

pragmatic approach to scientific representation has been adopted. As I have argued, the pragmatic accounts of representation, somewhat paradoxically, make apparent the limits of the representational paradigm as regards the epistemic value of modeling. Consequently, abandoning the representational approach to models, I suggest, actually enables us to pay attention to the very means of representation with which scientists build their models. As such this paves the way for applying semiotics to the present discussion on models and scientific representation, a possibility that has so far remained nearly unexplored in the mainstream philosophy of science.

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