Scientific Change and Partial Structures[1]

Otávio Bueno
Department of Philosophy
University of South Carolina
Columbia, SC 29208, USA

ABSTRACT

Any account of scientific change needs to accommodate two issues: conceptual and structural changes. In this paper, I argue that standard versions of scientific realism fail to accommodate such issues, and thus ultimately they do not provide an adequate account of scientific change. I then sketch, in terms of da Costa and French's partial structures approach, an account of scientific change that makes room for both issues. But to achieve this, the resulting proposal needs to abandon realism.

Keywords: scientific change, conceptual change, realism, anti-realism, partial structures, quasi-truth.

1. INTRODUCTION

Two important dimensions of scientific change are conceptual and structural changes. The formulation of a new theory involves the introduction of *new concepts* to explain empirical phenomena, and this process often leads to substantial reformulations in the old theory's conceptual framework. As a result, the *structures* (in particular, the models) used in the formulation of the old theory are replaced by new ones. Since the work of Kuhn [1962], these phenomena became crucial factors in the agenda of any reasonable account of scientific change.

As is also well known, scientific realism has been put forward to explain scientific change. According this view, scientific change is accommodated in terms of the search for approximately true theories. The scientific realist acknowledges that there might be some sort of loss when the scientific community shifts from one theory to another. However, well-established parts of the old framework – in particular, reference to certain entities introduced in explanations – are typically preserved (see, for instance, Popper [1963], Boyd [1990], and Psillos [1999]).

In this paper, I have two aims. Firstly, I shall recall and elaborate on some arguments to the effect that standard versions of scientific realism are undermined by the inadequacy of accommodating scientific change. In particular, the existence of conceptual change brings serious difficulties for scientific realism. Secondly, I will sketch an account of scientific change that is not open to this difficulty.

To achieve that, I'll employ a framework developed by da Costa and French to accommodate partiality of information in science (see da Costa and French [1990], [1993], and [2002]). Their main idea is to introduce a broader concept of structure (partial structure) and a weaker notion of truth (quasi-truth), appropriate for the "partialness" and the "openness" typically found in scientific life. The resulting account is called the partial structures approach. In terms of this conceptual framework, I shall sketch an alternative account of scientific change that accommodates conceptual and structural changes. The proposal, however, is not realist, given the difficulties faced by the latter view. And it is compatible with van Fraassen's constructive empiricism (van Fraassen [1980] and [1989]; see also Bueno [1997] and [1999]).

2. SCIENTIFIC REALISM AND CONCEPTUAL CHANGE

In the contemporary philosophical scene, there are several versions of realism. In this work, I shall focus on standard scientific realism, which can be roughly characterized by the claim that scientific theories are true (or approximately true) and their theoretical terms refer (see Popper [1963], Boyd [1990], and Psillos [1999]).

[1] Many thanks to Richard Boyd, José Chiappin, Igor Douven, Steven French, Ronald Giere, James Ladyman, Stathis Psillos, and Bas van Fraassen for helpful discussions and correspondence. This paper is an abridged version of a longer paper entitled "Understanding Scientific Change: Partial Reference and Partial Structures", forthcoming in *Synthese*, 2003.

But how successful is scientific realism? I think the proposal faces a number of difficulties; some of them have already been indicated in the literature (see, for instance, Laudan [1996]). A difficulty that is particularly pressing derives from the existence of scientific revolutions, which bring both conceptual change and change in the reference of theoretical terms. These two changes are, of course, related. The concepts introduced in a scientific theory are taken (by the realist) to have reference, and any change in the reference is taken as a change in the concepts used to refer to some part of the world.

But why is reference change a problem for scientific realism? Since one of the features of the proposal is that theoretical terms have reference, with a scientific revolution the realist will have to claim that the ultimate furniture of the world has changed. The world is no longer constituted by, say, phlogiston; now it is made of oxygen and other chemical elements. Mass is no longer an intrinsic, frame-independent property; it now depends on the frame of reference adopted and it is a relational property. But, of course, the world as such hasn't changed; only our description of it has. It is clearly unacceptable, from the realist perspective, to claim that a change in the conceptual framework used to describe the world amounts to a change in the world itself.

In response the realist could acknowledge that there are scientific revolutions, and thus that there are cases of reference change. However, the realist would *deny* that the latter undermine realism. At least such cases don't undermine a more sophisticated version of scientific realism, according to which scientific theories (being approximately true) have terms that only *partially denote* (and, in some cases, do not fully denote). In this way, the existence of scientific revolutions can be made compatible with scientific realism. Changes in reference arise from the fact that the terms involved only partially denote: they partially denote an entity x, partially denote another entity y. For example, they partially denote intrinsic mass (from Newtonian theory), partially denote relational mass (from Einstein's theory). So even if a term used prior to in a scientific revolution doesn't fully denote anything, at least it partially denotes something. And this allows the realist to explain why the theory in question successfully explained the phenomena (since partial denotation provides some continuity in theory change).

Of course, in order for this proposal to work, the realist has to provide an account of *partial denotation* that is compatible with realism. Boyd ([1990], p. 226; see also Psillos [1999]) has argued that such account is actually provided by Field (see Field [1973] and [1972]). Field has argued that the notion of truth can be defined in terms of partial denotation (of a term) and partial signification (of a predicate). Partial denotation and signification are taken by him as primitive. The idea is that the term mass, as used in Newtonian mechanics, partially denotes intrinsic mass, partially denotes relativistic mass, and doesn't fully denote either (Field [1973], p. 474). Similarly, an indeterminate predicate partially signifies each of its partial extensions (*ibid*., p. 477), that is, each of a number of disjoint sets of objects which constitute the predicate's extension.

Assuming these notions as primitive, Field then provides a semantics for indeterminate expressions in the following way (*ibid*., p. 477). First, the notion of structure is introduced. A *structure* for a sentence is a function that assigns each name in the sentence into some object, and each predicate into some set. Secondly, a structure S *corresponds* to the sentence if each name in the sentence partially denotes the object that S assigns to it, and each predicate partially signifies the set that S assigns to it. Field then applies the standard Tarskian semantics for each structure S in order determine whether the sentence is true or false relative to S (S-true or S-false). As he points out: "To say that the sentence is [S]-true is to say that it *would* be true if the denotations and extensions of its terms were as specified by [S]" (Field [1973], p. 477). A sentence is then true (false) if it is S-true (S-false) for every structure S that corresponds to it.[2]

The question is whether this account of truth in terms of partial denotation can be used by the scientific realist to overcome the problem posed by scientific revolutions. Despite Boyd's claim to the effect that it can, I think there are problems with this suggestion. First of all, strictly speaking, we don't have here an *account* of partial denotation. We have an account of *truth* in terms of partial denotation. But since the latter is taken as primitive, no account of it is forthcoming. Rather it is *assumed* that we have an understanding of partial denotation by some other means. Of course, I don't deny that we have some understanding of partial denotation. My point is only that the realist cannot use Field's proposal to provide an account of this notion.

[2] Using these notions, Field then provides an account of what he calls a *denotational refinement* of a term after a scientific revolution. This happens when the set of things the term partially denoted after the revolution is a proper subset of the set of things that it partially denoted before (Field [1973], p. 479). The denotational refinement indicates some continuity of reference across scientific revolutions.

Now every theory has its primitive notions. Why can't the realist simply assume (with Field) the notion of partial denotation as *primitive*? The problem with this move arises from the dialectics of the debate. The realist was led to introduce the notion of partial denotation because of the problem posed by scientific revolutions. The notion was introduced to avoid radical discontinuities in scientific change. Certain accounts of the physical world, although not entirely true, are not entirely false either. For the terms used by a theory before a scientific revolution at least partially denoted certain objects. And this makes room to accommodate the empirical success of such theories and some continuity between them.

However, for the realist's account to have any explanatory force, the crucial notion (of partial denotation) can't be *primitive*. After all, what the realist has to establish is that the relevant terms at best partially denote. In this way, the realist is only giving a name to one of the difficulties faced by his or her proposal. What we need is a proper *account* of this notion. And as we saw, this is something that Field's approach doesn't provide (and is not meant to provide either).

Moreover, as formulated by Field, partial denotation is *too weak* to support realism, since it is consistent with radical indeterminacy. In fact, as Field argues, *there is no fact of the matter* as to whether Newton's notion of mass denoted relativistic mass or proper mass (Field [1973], p. 468). If there is no fact of the matter as to what Newton's notion of mass actually denoted, the realist is in no position to claim that he or she has provided an explanation of the continuity between the two theories. On the contrary, the realist seems to have denied the existence of any grounds to claim that there is such continuity.

To overcome these problems faced by scientific realism, we need to consider a different framework: the partial structures approach.

3. PARTIAL STRUCTURES AND QUASI-TRUTH

The partial structures approach relies on three main notions: partial relation, partial structure and quasi-truth.[3] One of the main motivations for introducing this proposal comes from the need for supplying a formal framework in which the "openness" and "incompleteness" of scientific practice and knowledge can be accommodated in a unified way (da Costa and French [1990]). This is accomplished by extending, on the one hand, the usual notion of structure, in order to model the partialness of information we have about a certain domain (introducing then the notion of a partial structure), and on the other hand, by generalizing the Tarskian characterization of the concept of truth for such "partial" contexts (advancing the corresponding concept of quasi-truth).

In order to introduce partial structures, the first step is to formulate an appropriate notion of partial relation. When investigating a domain of knowledge, Δ, we formulate a framework to systematize and organize the information about it. This domain is then represented by a set D of objects, and is studied by the examination of the relations holding among D's elements. However, it often happens that, given a relation R on D, we do not know whether all the objects of D (or n-tuples thereof) are related by R. This is part and parcel of the "incompleteness" of our information about Δ, and is formally accommodated by the concept of partial relation. The latter can be characterized as follows. Let D be a non-empty set. An n-place *partial relation* R over D is a triple $\langle R_1,R_2,R_3\rangle$, where R_1, R_2, and R_3 are mutually disjoint sets, with $R_1 \cup R_2 \cup R_3 = D^n$, and such that: R_1 is the set of n-tuples that (we know that) belong to R, R_2 is the set of n-tuples that (we know that) do not belong to R, and R_3 is the set of n-tuples for which we do not know whether they belong or not to R. (Notice that if R_3 is empty, R is a usual n-place relation which can be identified with R_1.)

However, to represent the information about the domain in question, we need a notion of structure. The following characterization, spelled out in terms of partial relations and based on the standard concept of structure, supplies a notion that is broad enough to accommodate the partiality usually found in scientific practice. The main work is done by the partial relations. A *partial structure* S is an ordered pair $\langle D,R_i\rangle_{i\in I}$, where D is a non-empty set, and $(R_i)_{i\in I}$ is a family of partial relations defined over D.[4]

[3] This approach was first presented in Mikenberg *et al.* [1986]. Since then it has been extended and developed in several different ways; see, for instance, da Costa and French [1990], [1993], [2002], Bueno [1997] and [1999].

[4] The "partiality" of partial relations and partial structures is due to the "incompleteness" of our *knowledge* about the domain under investigation. With further information, a partial relation may become total. Thus, the partiality modeled here is not understood as an intrinsic, ontological "partiality" in the world. We are concerned with an "epistemic", not an "ontological" partialness.

We have now defined two of three basic notions of the partial structures approach. In order to spell out the last one (quasi-truth), we need an auxiliary notion. The idea is to use, in the characterization of quasi-truth, the resources supplied by Tarski's definition of truth. However, since the latter is only defined for full structures, we have to introduce an intermediary notion of structure to link it to the former. This is the first role of those structures that extend a partial structure A into a full, total structure (which are called A-normal structures). Their second role is model-theoretic: to put forward an interpretation of a given language and, in terms of it, to characterize basic semantic notions. The question then is: how can A-normal structures be defined? Let $A = \langle D, R_i \rangle_{i \in I}$ be a partial structure. We say that the structure $B = \langle D', R'_i \rangle_{i \in I}$ is an *A-normal structure* if (i) $D = D'$, (ii) every constant of the language in question is interpreted by the same object both in A and in B, and (iii) R'_i extends the corresponding relation R_i (in the sense that each R'_i, supposed of arity n, is defined for all n-tuples of elements of D').

Note that, given a partial structure A, there are a lot of A-normal structures. We need to provide constraints to restrict the acceptable extensions of A. In order to do that, a further auxiliary notion is required (Mikenberg *et al.* [1986]). A *pragmatic structure* is a partial structure to which a third component has been added: a set of accepted sentences P, which represents the accepted information about the structure's domain. (Depending on the interpretation of science that is adopted, different kinds of sentences are introduced in P: realists will typically include laws and theories, whereas empiricists will tend to add laws and observational statements about the domain in question.) A *pragmatic structure* is then a triple $A = \langle D, R_i, P \rangle_{i \in I}$, where D is a non-empty set, $(R_i)_{i \in I}$ is a family of partial relations defined over D, and P is a set of accepted sentences (which hold in A). The idea, as we shall see, is that P introduces constraints on the ways that a partial structure can be extended.

Our problem now is, given a *pragmatic* structure A, what are the necessary and sufficient conditions for the existence of A-normal structures? We can now spell out one of these conditions (Mikenberg *et al.* [1986]). Let $A = \langle D, R_i, P \rangle_{i \in I}$ be a pragmatic structure. For each partial relation R_i, we construct a set M_i of atomic sentences and negations of atomic sentences, such that the former correspond to the n-tuples that satisfy R_i, and the latter to those n-tuples that do not satisfy R_i. Let M be $\cup_{i \in I} M_i$. Therefore, a pragmatic structure A admits an A-normal structure if, and only if, the set $M \cup P$ is *consistent*.

Having said this, we are finally able to formulate the concept of quasi-truth. A sentence α is *quasi-true in a pragmatic structure* $A = \langle D, R_i, P \rangle_{i \in I}$ if there is an A-normal structure $B = \langle D', R'_i \rangle_{i \in I}$ such that α is true in B (in the Tarskian sense). If α is not quasi-true in A, we say that α is *quasi-false in A*. Moreover, we say that α is *quasi-true* if there is a pragmatic structure A and a corresponding A-normal structure B such that α is true in B (according to Tarski's account). Otherwise, α is *quasi-false*.

Intuitively, a quasi-true sentence α does not describe completely the domain under investigation, but only an aspect of it – the one modeled by the relevant pragmatic structure A. After all, there are several different ways in which A can be extended to a full structure, and in some of these extensions α may not be true. As a result, the notion of quasi-truth is strictly weaker than truth: although every true sentence is (trivially) quasi-true, a quasi-true sentence is not necessarily true (since it may be false in certain extensions of A). This is an important feature of this notion.

To illustrate the use of quasi-truth, let us briefly consider an example. As is well known, Newtonian mechanics is appropriate to explain the behavior of bodies under certain conditions (roughly speaking, if the speeds in question are "low" in comparison with that of light, the bodies are not subject to strong gravitational fields etc.). And with the formulation of special relativity, we learnt that if these conditions are not satisfied, Newtonian mechanics is false. In this sense, these conditions specify a family of partial relations, which delimit the context in which the theory holds. Although Newtonian mechanics is not true (and we know under what conditions it is false), it is *quasi-true*; that is, it is true in a given context, determined by a pragmatic structure and a corresponding A-normal one, which satisfy the conditions mentioned above (see da Costa and French [1993]).

It is time now to return to the discussion of scientific change. As we shall see, the latter can be addressed in a new way if we explore the formal resources provided by the above framework.

4. PARTIAL DENOTATION AND SCIENTIFIC CHANGE

The main idea of the present view is that scientific theories need not be true to be good, but only quasi-true. It is, thus, an anti-realist account, since truth is not an aim of science (see van Fraassen [1980]). In scientific change, some structure is lost because typically we have only a *partial* structure preservation. Only the parts of the theory that were *empirically* well supported are preserved. This aspect clearly sides with empiricism.

But can we formally capture the intuition underlying this claim? In terms of the partial structures approach, I think a positive answer can be given to this question. The notion of partial structure preservation can be formally represented by a partial isomorphism between the structures of the old and the new theory. More formally,[5] let $S_1 = \langle D, R_i \rangle$ and $S_2 = \langle D', R'_i \rangle$ be two partial structures, where $R_i = \langle R_1, R_2, R_3 \rangle$ and $R_i' = \langle R'_1, R'_2, R'_3 \rangle$ are, say, binary partial relations. We say that a (partial) function $f: D \rightarrow D'$ is a *partial isomorphism* between S_1 and S_2 if (i) f is bijective, (ii) for every x and $y \in D$, $R_1xy \leftrightarrow R'_1f(x)f(y)$ and $R_2xy \leftrightarrow R'_2f(x)f(y)$. (Thus, if the third components, R_3 and R'_3, are empty, we obtain the usual notion of isomorphism.)

This notion of partial isomorphism can then be used to provide an account of partial structure preservation in scientific change, and it thus accommodates an important aspect of scientific practice. For example, there is no counterpart of Descartes's theory of *vortices* in Newton's mechanics. However, Descartes's theory of *inertia* found its way into Newton's. Hence, *some* structure was preserved in this theory shift, and the partial isomorphism between the models of the two theories accommodates that. The R_1 and R_2 components for which there was enough empirical evidence are carried over, by the partial isomorphism, into the models of the Newtonian theory. However, the R_3 components, for which there wasn't enough evidence, are left behind (see Bueno [2000]).

The partial structure preservation accommodates the two dimensions of scientific change: structural and conceptual change. The existence of structure change after a scientific revolution is straightforwardly described in terms of the partiality of the isomorphism that holds between the models of the theories under consideration. As noted above, some structure is typically carried over in scientific change, but some is inevitably lost. Conceptual change, on the other hand, is usually associated with structure change. With the introduction of new structure, new concepts are formulated.[6] These concepts are then used to explore the domain of the new theory after the scientific revolution. Moreover, with structural losses, concepts are also lost. As noted above, there is no room for Cartesian vortices in the Newtonian theory.

Turning now to scientific realism, as we noted, one of the problems of this view came from the existence of scientific revolutions. And an attempt was made of overcoming the difficulty with the notion of partial denotation. Now, with the adoption of partial structures, the present proposal provides an *account* of partial denotation, without having to take the latter as primitive. We can say that a term *t partially denotes* entities o_1 and o_2 if t occurs in a sentence M that is quasi-true, and M is true if it is about o_1, and is false if it is about o_2. For example, consider the sentence, "Mass depends on the frame of reference" (M). Clearly, M is quasi-true: it is true in the context of relativity theory; moreover, it is false in the context of Newtonian mechanics. Thus, the term mass partially denotes relativistic mass, partially denotes intrinsic mass. As we saw, this is exactly the same result obtained by Field's account. And the notion of partial denotation presented here is similarly weak, since it is compatible with the *radical indeterminacy* of the notion of mass: there is no fact of the matter as to whether Newton's notion of mass denoted relativistic mass or intrinsic mass. However, as opposed to Field's approach, we don't have to introduce the notion of partial denotation as primitive; the notion can be characterized in terms of quasi-truth. So, by moving to the partial structures approach, and by adopting an empiricist view, the difficulties faced by scientific realism can also be accommodated.

5. IN CONCLUSION

Using the partial structures framework, it is thus possible to provide an account of scientific change that handles both conceptual and structural changes. Given the difficulties faced by the realist (discussed above), the account provided relinquishes realism. And given the features of the account, it is entirely compatible with an empiricist stance – in particular, with van Fraassen's constructive empiricism (see Bueno [1997] and [1999]).

As we saw, in terms of this framework, an account of *partial denotation* in terms of partial structures can be provided. And the account ultimately supports empiricism, since only reference to components of the *empirical* domain is "preserved" in theory change (with regard to theoretical components, they only *partially denote*, since

---

[5] See French and Ladyman [1999], and Bueno [1997].

[6] The introduction of new structures can be represented by the partial structures framework by the existence of a *partial embedding* from a model of a theory T_1 into a model of a theory T_2; i.e. by establishing a partial isomorphism between a model of T_1 and a substructure of a given model of T_2. This allows the possibility that T_2 has *more* structure than T_1 (see Bueno [2000]).

scientific theories are taken to be at best quasi-true). But the account also accommodates *structural losses* that so often are found in science. In terms of the existence of *partial isomorphisms* between the structures of the new and old theories, an account of partial structural preservation in science is presented. In this way, a clear sense can be made to the idea that only *some* structure is carried over in scientific change. As a result, an argument for an empiricist view of theory change is put forward. Given the structuralist and empiricist features of this view, I call the resulting proposal *structural empiricism* (see Bueno [1999]).

REFERENCES

Boyd, R. [1990]: "Realism, Approximate Truth, and Philosophical Method", in Savage (ed.) [1990], pp. 355-391.

Bueno, O. [1997]: "Empirical Adequacy: A Partial Structures Approach", *Studies in History and Philosophy of Science 28*, pp. 585-610.

Bueno, O. [1999]: "What is Structural Empiricism? Scientific Change in an Empiricist Setting", *Erkenntnis 50*, pp. 59-85.

Bueno, O. [2000]: "Empiricism, Mathematical Change and Scientific Change", *Studies in History and Philosophy of Science 31*, pp. 269-296.

da Costa, N.C.A., and French, S. [1990]: "The Model-Theoretic Approach in the Philosophy of Science", *Philosophy of Science 57*, pp. 248-265.

da Costa, N.C.A., and French, S. [1993]: "Towards an Acceptable Theory of Acceptance: Partial Structures and the General Correspondence Principle", in French and Kamminga (eds.) [1993], pp. 137-158.

da Costa, N.C.A., and French, S. [2002]: *Partial Truth and Partial Structures*. Oxford: Oxford University Press, forthcoming.

Field, H. [1972]: "Tarski's Theory of Truth", *Journal of Philosophy 69*, pp. 347-375.

Field, H. [1973]: "Theory Change and the Indeterminacy of Reference", *Journal of Philosophy 70*, pp. 462-481.

French, S., and Ladyman, J. [1999]: "Reinflating the Semantic Approach", *International Studies in the Philosophy of Science 13*, pp. 103-121.

French, S., and Kamminga, H. (eds.) [1993]: *Correspondence, Invariance and Heuristics: Essays in Honour of Heinz Post*. Dordrecht: Reidel.

Kuhn, T. [1962]: *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press. (A second, enlarged edition was published in 1970.)

Laudan, L. [1996]: *Beyond Positivism and Relativism*. Boulder: Westview Press.

Mikenberg, I., da Costa, N.C.A., and Chuaqui, R. [1986]: "Pragmatic Truth and Approximation to Truth", *The Journal of Symbolic Logic 51*, pp. 201-221.

Popper, K.R. [1963]: *Conjectures and Refutations*. London: Routledge and Kegan Paul.

Psillos, S. [1999]: *Scientific Realism: How Science Tracks Truth*. London: Routledge.

van Fraassen, B.C. [1980]: *The Scientific Image*. Oxford: Clarendon Press.

van Fraassen, B.C. [1989]: *Laws and Symmetry*. Oxford: Clarendon Press.