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INTERACTIVE REPRESENTATIONS

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Abstract

In this paper we argue that philosophy of science is in need of a comprehensive and deep theory of scientific representation. We contend that such a theory has to take into account the conceptual evolution of the notion of representation in the empirical science and mathematics. In particular, it is pointed out that the category-theoretical notion of an adjoint situation may be useful to shed new light on the intricate relation between the empirical and the theoretical by showing that scientific representations do not mirror reality but are to be conceived as devices for establishing scenarios for a variety of possible representational interventions and interpretations.

Keywords

< Representation > < Interaction > < Adjoint Situation > < Galois Connection >

1. *Introduction*

Traditionally, two questions have been asked about representation: first, what conditions, more or less intrinsical ones, have to be satisfied in order that some kind of object represents some other kind of object? Secondly, what guarantee do we have that representations correspond or are adequate to the objects they represent? According to Rorty, a large part of modern philosophy tried to answer the second question (cf. Rorty 1980, 45f). For him, this has led to a deadlock in epistemology and philosophy of science since it pushes into a hopeless maze of pseudoquestions without answers. Accordingly, the traditional epistemological accounts based on representation should be replaced by an approach based on the notion of negociation and interpretation. In this paper we will not address this kind of radical anti-representationalism. Be it sufficient to say, that it is based on a rather primitive concept of representation identifying representation with some kind of copying or mirroring. This kind of representation is indeed rather unim-

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portant for science, and therefore for philosophy of science as well. But this is not the kind of representation we are interested in.

There are other philosophical trends dealing with representation that are a bit more sympathetic with that notion. These accounts characterize themselves as *deflationary*. Although they do not doubt that representation has some role in science they deny that there can be an interesting philosophical *theory* of representation. In other words, they consider it sufficient to deal with the first question mentioned above. For instance, recently Mauricio Suárez maintained:

> Representation is not the kind of notion that requires a theory to elucidate it: there are no necessary and sufficient conditions for it. We can at best aim to describe its most general features - finding necessary conditions will certainly be good enough. Second, it entails seeking no deeper features to representation other than its surface features: the representational force of a source is one such irreducible feature; the capacity to allow surrogate reasoning is another. (Suárez, 2004: 771).

For several reasons we disagree with Suárez:

(1) First, there is a non-sequitur in his argument: even if one grants that there are no "necessary and sufficient conditions" for the notion of representation, this does not entail that there is no theory of that notion. The notions of number, space, causality, gravity, and many others may lack "necessary and sufficient conditions", but this is no hindrance to the existence of theories about them: theories of numbers, space, or causality are cognitive endeavours that perfectly make sense but do not assume that their key notion can and should be characterized by a set of necessary and sufficient conditions.

(2) If representation were a philosophically uninteresting notion there would not be much left of philosophy of science: after all, what is a scientific theory than a kind of representation of empirical phenomena? And if the notion of a scientific theory is considered as a notion devoid of theoretical interest for philosophy of science, what would be left?

(3) Another reason why we cannot avoid theorizing about the notion of scientific representation is that in philosophy of science, let alone the broader domain of philosophy in general, it is still far from clear what is to be understood by representation.

Finally, some accounts of Science Studies deny that the theory of representation is a theory, since according to them there is no corresponding natural kind of that could be studied by this theory and that comprises thus different things as geometrical representations and

material 3-dimensional representation (cf. Rheinberger 2003). According to these authors, there is no argument or evidence in favour of the existence of a natural kind "representation". Consequently, it is sufficient to analyse the realms in which something represents something without aiming to develop a theory, which describes the properties of representations in general or formulates a general definition of that concept. In this paper we want to address that challenge by showing that the existence of such a natural kind can be maintained. In our opinion there are quite enough reasons to assume that there is still some work to do for a philosophically non-trivial *theory* of scientific representations. We claim that the "guarantee" of representational adequacy does not reside in the elusive fact of a correspondence based on something external but on the kind of interactive practices determined by the consequences of a practical nature. The representational theory in question is concerned with the forms of these practices.

The outline of the paper is as follows: first, we let recall some kinds of representations that have been considered as important, characteristic or otherwise typical for scientific representations. We will distinguish between four kinds. Among them, the fourth may be new. It may be characterized by the fact that it strongly emphasizes the role of active and constructive *interpretation* in dealing with scientific representation. Scientific representations do not give us a direct image or picture of the represented. They do not speak for themselves, and they do not show anything in a direct way. Hence, in section 3 we intend to capture the *interactive* or interpretative aspects of representations in a new way by employing the notion of an *adjoint situation*. Special adjoint situations, the so called Galois connections may help to elucidate the intricate relation between the empirical and the theoretical as it appears in scientific representations. The concept of Galois connection is imported from the mathematical theory of categories. Its application shows once more the importance of mathematics for a non-trivial theory of representations. In section 4, we conclude with some general remarks on the agenda of a comprehensive theory of scientific representation. We argue that scientific representations are to be considered as ways of opening a space of representational possibilities - which we will call *scenarios of representation* -that cannot even be imagined without them-. This constructive role of representations has, of course, not gone unnoticed up to now, but it has been seriously underestimated.

2. *Kinds of Representations*

One of the most superficial difficulties of the philosophical discourse on representation is that "representation" is a term with many meanings. Therefore, confusion is to be expected if one does not clearly distinguish what is to be understood by "representation". The problem of distinguishing between the various meanings of the term "representation" is of particular relevance for a theory of scientific representation as not all notions of representation presently in use are useful for such a theory.

The following list shows various variants of the notion of representation more or less ordered according to its growing degree of sophistication - and usefulness for a theory of scientific representations:

Representations based on

Mirroring	Isomorphic Representations
Direct Structural Similiarity	Homomorphic Representations
Indirect Structural Correlations	Homological Representations
Re-representations	Adjoint Representations

2.1 *Isomorphic Representations.*

There is not much to say about isomorphic representation. This is the variant of representation preferred by radical anti-representationalists such as Rorty. If W is represented isomorphically by M, the W and M may be considered as copies of each other. One may serve as the substitute of the other. Copies of maps, plans and graphics are typical examples of isomorphic representations. In science, isomorphic representations play a rather limited role, e.g. in the theory of *Gelstalt* (Köhler 1920). Only a non-scientist can harbour the idea that a physical or chemical formula can serve as a copy of the event, process, or stuff it is intended to represent.

> Nevertheless, one of the advantages of this concept of representation is that it allows for a precise formulation that renders it interesting for philosophy of science. Thus, some authors maintain that a model represents the system it represents only in some scientifically relevant aspects, but not in all (Bueno 1997, French 2003). This would permit to reconcile (partial) isomorphic representations with the existence of inexact theories or models, and maybe even with those that are internally inconsistent (Da Costa and French 2000). Even if this could be maintained, the "partial account" of representation does not take into account the symbolic power of representations exhibited by the fact that representations are asymmetric, refer to singular (not necessarily individual) objects, and may be false (cf. Suárez, 2003; Callender and Cohen, 2005).

2.2. *Homomorphic Representations.*

More interesting kinds of representations are met when we enter the realm of homomorphical representations. The idea of homomorphic

representation may be traced back to Helmholtz, according to whom there is a homomorphism between the world W of the things in themselves on the one hand, and the realm S of our sensations on the other (Helmholtz 1879)[1]:

$$W \Rightarrow S$$

Although we will never know how things really are, our sense organs and, as may be considered as structure-preserving homomorphisms which give us a faithful picture of the structural relations of W.

A less metaphysically loaded version of epistemology based on the notion of structure-similarity is provided by the theory of representational measurement inaugurated by Stevens and further developed by Suppes and his school (Krantz *et al.* 1971/89/90). According to this approach, measuring may be conceived as establishing a structure-preserving homomorphism between the empirical realm of objects to be measured and some appropriate numerical realm.

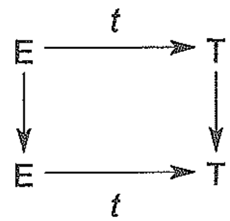
Although the notion of a homomorphic representation is certainly useful, it may be considered to be too narrow if we take a closer look on the representational practice of real science. One may doubt if representation in science can always be cast in the framework of structure preserving maps (Ibarra & Mormann 1997). Nevertheless, as Giere has claimed, it seems plausible in principle to preserve something of the idea of structural resemblance in the concept of representation (Giere 1988), resemblance with respect to a certain number of relevant properties to a some degree. In his opinion, there is no general answer to the question on what are the properties to which the represented and the representing object have to resemble and to what extent, since the particular conditions of each case determine what counts as relevant similarity. Once the context has been specified, i.e., once certain boundary conditions that determine what is to be explained or predicted have been outlined, what is the degree of admissible error, etc., the necessities of the case in question offer a sufficient base for determining the type or degree of similarity that is needed (Teller 2001). The concept of similarity representation seems to be too narrow to capture the idea of scientific representation for much the same reason as the concept of homomorphic representation. In some cases the models may be similar to the objects represented but not always (Hughes 1977). Hence, it may be expedient to introduce the more general framework of *homological representations.*

2.3. *Homological Representations.*

This kind of representations may be motivated by the well-known dictum of Hertz in his *Introduction to Mechanics* by which he described the general procedure of scientific representations as follows:

> We make mental images or symbols of the exterior objects in such a way that the logically necessary consequences of the images are always images of the naturally necessary consequences of the objects. In order that this may be possible at all, there must exist certain correlations between nature and our mind. We are taught by experience that this requirement can be satisfied and that these correlations actually exist. (Hertz, 1894: 1)

The following diagram may be used to capture the essential structure of Hertz's account:



Here, the horizontal lines represent the "theoretical translation" of empirical facts into their theoretical counter parts, for example, the correlation of some chemical stuff with some of its chemical formulas. Establishing this correspondence may be quite complicated but let us ignore the possibly large distance between E and T for the moment. The left vertical arrow represents Hertz's relation of "natural necessity", and the right vertical arrow corresponds to his relation of "logical necessity" (Ibarra & Mormann 2000).

In contrast to homomorphical representations, in homological representations there is only a rather indirect and remote correlation between the representing and the represented domain. For instance, one may say that in quantum mechanics a system is represented by its Schrödinger equation but certainly this representation is quite indirect and of a different kind than the representation provided by a structure-preserving homomorphism in the sense of Suppes' representational theory of measurement.

Relying on the Greek etymology of the words "homomorphism" and "homology", we may say that homologous representations no longer preserve the "*morphe*", i.e., the "form", but rather intend to preserve some kind of abstract "*logos*". This does not mean that homomorphical and homological representations belong to two categorically distinct realms, but certainly the latter are much more general. Hence, in order not to stretch too much the notion of homomorphy we prefer to introduce a new label for this kind of representations. Moreover there are other compelling reasons from mathematics to distinguish between the two kinds (Ibarra & Mormann 2000).

Informally, homological representations may be characterized as a sort of "representation at a distance", or, if this is possible in English, we may speak of "distanced representations". We believe that indeed the notion of representational distance is important for a comprehensive theory of scientific representations. Representation in science is almost never an one-step affair: we do not leap in one step from the represented domain to the representing as it may suggested by Hertz's description quoted above. Rather, there are more or less complicated *representational chains* connecting one pole of the over-all representational relation with the other one. Hence, as was already recognized by Peirce, representations never exhaust their objects. We represent with the aid of representational chains that generate new representations from the old ones and new interpretations for new objects:

> A sign stands for something to the idea which it produces, or modifies. Or, it is a vehicle conveying into the mind something from without. That for which it stands is called its object; that which it conveys, its meaning; and the idea to which it gives rise, its interpretant. The object of representation can be nothing but a representation of which the first representation is the interpretant. But an endless series of representations, each representing the one behind it, may be conceived to have an absolute object at its limit. The meaning of a representation can be nothing but a representation. In fact, it is nothing but the representation itself conceived as stripped of irrelevant clothing. But this clothing never can be completely stripped off; it is only changed for something more diaphanous. So there is an infinite regression here. Finally, the interpretant is nothing but another representation to which the torch of truth in handed along; and as representation, it has its interpretant again. (C. Peirce, CP 1.339)

More generally, in the representational practice of science, representations do not live in insulation, rather there may be combinated and concatenated in various ways. Hence, investigating these combinatorial aspects of representations is a central task of a general theory of representation. We claim that the framework of distanced representations, i.e., homologous representations, is better suited for this purpose than the overly narrow approach of structure-preserving homomorphisms.

2.4. *Adjoint Situations.*

Distanced representations for which the represented domain and the representing one are remote from each other are in need of *interpretation*. That is to say, there is no short-cut "automatic" meaning to be grasped from some complicated representational chain. The elucidation of this complexity seems to us a major task in philosophy of science. For this purpose, we want to introduce the notion of an adjoint situation or Galois connection.

When we let conceive a scientific theory as a kind of Hertzian representation t: E $\longrightarrow$ T of an empirical domain E by some kind of theoretical or conceptual domain T we observe that this is only half of the story. Actually, we are not only dealing with the representations t(e) of the empirical by the theoretical, but also with a "representation" of the theoretical by the empirical. For instance, if we build up a complicated experimental set-up then it is assumed that this material machine somehow realizes our theoretical assumptions. That is to say, we not only have a correspondence of the type

$$E \xrightarrow{t} T$$

but there is also a correspondence in the opposite direction:

$$T \xrightarrow{e} E$$

which may be considered as a sort of empirical re-representation or interpretation function.

In an informal sense, this was already stated by Duhem, who described the complex relation between "theoretical" or "symbolic facts" on the one hand, and "empirical facts" on the other (Duhem 1906). Other physicists and philosophers spoke of the "swing" or the "dialectic" between the empirical and the theoretical (Margenau 1935). All this is certainly helpful, but the elucidation provided by this kind of arguments remains restricted to a purely metaphorical level.

It is now interesting to observe that in the realm of mathematical representations, there is the notion of *adjoint situation* which applies exactly to the situation described above (Goldblatt 1978). As an empirical fact, so to speak, many important homological (functorial) representations

$$A \xrightarrow{\mathcal{F}} B$$

come along with a ready-made counter-representation or re-representation that goes in the opposite direction:

$$B \xrightarrow{\mathcal{G}} A$$

We hope to make plausible that this is not a mere co-incidence. In any case, whether we like it or not, it is a fact that mathematical representations play an important role in science. And not only this: mathematical notions such as isomorphism and homomorphism play an

important role also in the philosophical theories of representation. Thus it is plausible to assume that the evolution of representational concepts in mathematics will influence sooner or later other realms of knowledge in which representations already play an important role. At least, this is the leading hypothesis on which this paper is based which, obviously, flies in the face of those accounts according to which there is no need for a "theory" of representation. In contrast, we contend that philosophy of science is in urgent need of such a theory, since in mathematics has taken place a development that has profoundly influenced our conception of representation, namely, the formulation of a general concept of adjoint situation. Without doubt, philosophy of science —as a theory of scientific representation— sooner or later will have to deal with it. According to Goldblatt and many other authors, the "isolation and explication of *adjointness* is perhaps the most profound contribution that category has made to the history of general mathematical ideas." (Goldblatt, 1978: 439)

The basic data for an adjoint situation, or adjunction, comprise two domains $\mathcal{C}$ and $\mathcal{D}$, to be called "universes of discourse" ("categories"), and two representations ("functors") $\mathcal{F}$ and $\mathcal{G}$ between them,

$$\mathcal{C} \underset{\mathcal{G}}{\overset{\mathcal{F}}{\rightleftarrows}} \mathcal{D}$$

enabling an interchange of the conceptual apparatuses of $\mathcal{C}$ and $\mathcal{D}$. In terms of category theory, this interchange is precisely defined as a complex network of relations between the objects, relations, and morphisms of one category and the other. In the next section we will treat in some more detail this complex for the simplest type of adjoint situations that occur in nature, to wit, the so called Galois connections that are defined as adjoint situations between order structures that may be conceived as very simply structured categories. Even for them, the resulting network of conceptual relations turns out to be far from trivial. In general, it should be noted that an adjoint situation is almost never symmetric, rather there is a crucial asymmetry between the categories $\mathcal{C}$ and $\mathcal{D}$, or more precisely, between the functors $\mathcal{F}$ and $\mathcal{G}$. Hence, $\mathcal{F}$ is called the right adjoint functor (of $\mathcal{G}$), and $\mathcal{G}$ is called the left adjoint functor (of $\mathcal{F}$). Then the adjoint situation described above is denoted by ($\mathcal{G}$, $\mathcal{F}$). The context in which adjoint situations arise may often be described as follows: One starts with a one sided functorial representation $\mathcal{C} \xrightarrow{\mathcal{F}} \mathcal{D}$. Then, under certain conditions on $\mathcal{C}$ and structural requirements on $\mathcal{F}$ one may show that $\mathcal{F}$ has a left adjoint $\mathcal{D} \xrightarrow{\mathcal{G}} \mathcal{C}$. This is the general format of what has been rightly called one of the most important single theorems of category theory, the so called adjoint functor theorem (cf. Borceux, 1994; Theorem 3.3.3: 109). The point of this theorem is that the existence of a left adjoint for $\mathcal{F}$ establishes important relations between the structure of $\mathcal{C}$ and $\mathcal{D}$ which hardly could be achieved without it. In the next section we are going to show in some more detail how this works for the special case of $\mathcal{C}$ and $\mathcal{D}$ understood as the realms of the empirical and the theoretical, respectively.

Mathematical representations may be considered as typical for scientific representations in general. We think that this is not a mere coincidence. Rather it reveals an essential characteristic of the relation between mathematics and empirical science. Today, this relation is not a hot topic in philosophy of science. Once upon a time, things were different: for instance, Cassirer in the beginnings of the last century maintained that the elucidation of the interrelation between empirical science and mathematics belonged to the most important task of philosophy of science. According to him,

> The concepts of mathematics and the concepts of the empirical sciences are principally of the same kind. (Cassirer, 1907)

And more, these principles are of a representational nature. This should not be interpreted flatly as an attempt to disolve the empirical sciences into mathematics. Cassirer's point is that both areas use the same representational methods (Mormann, 2004). In this paper we do not want to argue for this philosophical thesis. Rather, we collect some empirical evidence, so to speak, that he may have been right.

3. *Re-representing and Interpreting Representations*

Representing something by something is not a goal in itself. This insight is not new, and recently it has been emphasized by Giere, who pointed out that representation should be considered as a four-place relation (Giere, 2004). The expression M represents W should be considered as shorthand for:

S uses M to represent W for purpose P

Here, S may be taken as the scientific community or a part of it, i.e., the "subject" of the representation; M may be taken as the a model, through which a chunk of the world W is represented for certain purposes P, for instance for purposes of prediction or technical realization. In this section we want to concentrate on the fact that for any purpose P and any subject whatsoever - except, perhaps, for a godlike transcendental one - never gives a *direct* representation that can be instantaneously used for

purpose P. Rather, the subject S has to invest some interpretative *work* in order to render the representation useful. And this work can indeed be hard work weaving together the mathematical and the empirical aspect of the part of the world that is "under representation".

Once again, the example of mathematical representation clearly shows the point: representing a molecule or any other particle system by its Schrödinger equation is not very useful in itself. Rather, one has to invest a lot of work to render the abstract mathematical representation via Schrödinger equation useful, i.e., to squeeze some juice out of the general representational framework. In general terms, one may say that the Schrödinger representation, as any other representation, has to be *interpreted* in certain ways.

As we already said, one is often content to describe this interpretation in more or less informal terms, for instance as a kind of dialectic between the empirical and the theoretical, or as Margenau's "swing" moving from the empirical to the theoretical and back to the empirical. We readily admit that these informal descriptions have their merits, but they do not suffice for a theory of representations. That is to say, what we are aiming at is a theoretical model of how this kind of "swing" works.

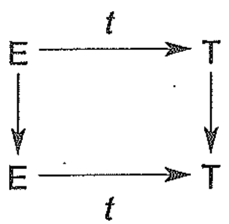
First of all one, may observe that these metaphors point at a concept of representation that is distinct from the traditional one which conceives representation as a kind of doubling of something objective that can be accessed independently, rendering representation sort of *Ersatz* of that objective being. They point at a concept of representation by which something is attempted to be made present, to ensure its presence, or to constitute it. "To make something present" is something quite different from making one thing - the representing - correspond to some already existing thing - the represented-. According to these metaphorical accounts of representation we are discussing, representation is not an object, but an activity or a process. They are rather close to the concept of representation, or, better, "presentation" once proposed by Brentano: "I don't understand as "presentation" that what is presented but the very activity of presentation." (Brentano, 1874)

Moreover, in this perspective representation is not a construct that is to be conceived as *ersatz* of an allegedly original object - which is to be represented in order to become acquainted with - but rather a relational activity in which the two relata of the representational relation co-constitute each other. The representation constitutes its two poles without that one precedes the other. *Pace* Hacking we do not intervene to be able to represent or represent in order to intervene (Hacking, 1983); rather we represent in an intervening manner or we intervene representationally. The representational activity does not describe the objects or states of the world but intervenes as operating on this world. Investigations related to the construction of robots show that the world maps they construct simultaneously describe the world and control the behaviour of the agents (Clark, 1997). The problem is how to elucidate this structure of representational activity as a constitutively relational activity.

Once again, the theory of mathematical representations comes to the rescue. In similar ways as the mathematical concepts of structure-preserving homomorphisms or homological functórs help to elucidate the notions of direct structural similarity and indirect structural correlations, the notion of an *adjoint situation* may help to elucidate the idea of interpreting or re-representing representations or, as we call them in the following, interactive representations. As we already stated, adjoint situation is the key notion of the foundational discipline of category theory (Mac Lane, 1986). Category theory may be characterized as a general theory of representations. Hence, it is certainly not totally absurd to conjecture that that notion may have some interest for the general theory of scientific represesentations we are aiming at.

For our purposes, the basic idea of adjoint situations or Galois connections, as they are sometimes called, may be explained as follows:

Assume E to be the domain of the empirical, and T to be the domain of the theoretical. Then, in an abstract and rather superficial way, the representational practice of science may be conceptualized as being based on the representation of E in T. We use the Herz diagram to describe this activity:



Then, the general correspondence between "nature" and "mind", or as we would prefer to call it, the correspondence between the empirical and the theoretical domain may be expressed by the assertion that t is a structure preserving map of the following kind:

$$e_1 \leq_e e_2 \Rightarrow t(e_1) \leq_t t(e_2)$$

Here, the relation $\leq_e$ is to be interpreted as a kind of causal relation such that $e_1 \leq_e e_2$ is to be read as "the empirical fact e_1 brings about the empirical fact e_2". Correspondingly, the theoretical relation "$t(e_1) \leq_t t(e_2)$" is to be read as "the theoretical description $t(e_1)$ of e_1 entails the theoretical description $t(e_2)$" or something like this. We intentionally leave open what is to be understood precisely by "empirical

fact" and "theoretical description" here. The point is that one has two distinct levels ("the empirical" vs. "the theoretical") related by a structure-preserving map.

But actually there is more in such a representational situation. Given a theory, not only we have theoretical representations t(e) of empirical facts or events e, we also have empirical interpretations of theoretical facts or prediction. We have a kind of interaction between E and T. That is to say, given a theoretical fact or prediction x, we have to know what may count as its empirical counterpart e(x). For instance, applying the conceptual apparatus of our theory T, we may come to make a certain prediction. But in order for this prediction to have any empirical relevance we have to know what counts as its empirical realization. And often this empirical counterpart is not "out there", but has to be constituted as well.

From our point of view it is inadequate to conceive representations as static and completed structure that somehow mirror the empirical located in some external world. It is more expedient to subscribe to a more dynamical and incomplete idea of representation that allows to conceive it as a kind of guide, a blue print for the practical action of scientific investigation. In the framework of T, we produce a representation of something to use it in a practical manner and to seek different possible interpretations, feed-backs of it in E. Once one has obtained this information, the representation is modified and one goes on to produce a new representation. In this way what is usually understood as representation plays a double function in the representational process: on the one hand representation appears as that which is represented by something; on the other hand, it appears as that which is representing something in the strict sense. We succeed in identifying something as a representation of something (in the traditional sense) only after we have moved between the region E and the region T of the representational space several times, thereby carrying out, as Margenau once called it (cf. Margenau, 1935), some kind of "swing" between the two realms. It is this dynamical character of representation that is ignored by the traditional concepts of representation that look at it mainly from the perspective of some kind of structure preservation. And exactly this dynamical character of scientific representation we aim to capture by our concept of representation that is based on the idea of adjoint situations. Indeed, the problem is how the correlation between t and e has to be conceptualized in order to model something like the interpretative back and forth moving of real science.

Let us assume a perfect balance between the theoretical and the empirical. This means, that we have to take into account not only the *theoretical* representation t: E $\longrightarrow$ T but also an opposite *empirical* representation e: T $\longrightarrow$ E. The map t may be characterized as "idealization", while the map e as an empirical "constitution". A simplistic answer to the correlational problem just mentioned would be that there is a 1-1-relation between t and e. That is to say, t and e are inverse to each other: in this case, exactly one theoretical fact corresponding to exactly one empirical fact and viceversa. Obviously, this idea is much too simple.

Interestingly, the theory of adjoint situation or Galois connections offers a more sophisticated answer. More precisely, it even offers *two* answers and both seem to be pretty plausible. Unfortunately, we cannot take an ecumenic stance, so to speak, since their conjunction leads to the overly simplistic account that there is a perfect 1-1 correspondence. Now let us come to the first proposal inspired by the theory of adjoint situations:

A theory (T, E) is *empirically fully adequate* if and only if

(I) $t(a) \geq x \Leftrightarrow a \geq e(x)$

Informally the equivalence may be stated as:

The *theoretical representation* t(a) of the empirical fact a *implies* the *theoretical fact* x

IFF

The *empirical fact* a *brings about* the *constitution* e(x) of the *theoretical fact* x.

Meditating a bit on this bi-conditional reveals that at least *prima facie* it does not appear to assert an unreasonable requirement for a perfect empirical theory. It establishes a reasonable correlation between the domains of empirical and theoretical facts. Moreover, it can be shown by mathematical examples that adjunctions of this kind are quite common and reveal interesting relationships between the two domains. But things are more complicated, since the just mentioned correlation between the theoretical and the empirical is not the only possible one. Instead of (I) we could have chosen the following definition:

A theory (T, E) is *empirically fully adequate* if and only if

(II) $e(x) \geq a \Leftrightarrow x \geq t(a)$

Informally this can be stated as follows:

The *empirical representation* e(x) of the theoretical fact x *brings about* the empirical fact a

IFF

The *theoretical fact* x *implies* the idealization t(a) of the empirical fact a.

It may be not quite obvious that the two bi-conditionals (I) and (II) are *not* equivalent. On the other hand, it can be proved immediately that the conjunction (I) *and* (II) implies that the empirical domain E and the theoretical domain T are isomorphic, what certainly is unacceptable. This means, that the concept of an adjoint situation or Galois connection is not symmetric. Mathematically spoken, in the case (I) the representation e is called the *right* or *upper* adjoint, and t is called the *left* or *lower* adjoint. In the second case, the representation e plays the role of the *left adjoint*, while t is the *right adjoint*. That both cases are different is expressed in mathematical terms by the statement that *right adjoints* and *left adjoints* are to be distinguished.

Hence in a general theory of representation we are confronted with the fact that we have to distinguish between the two cases if a representation $\mathcal{F}: \mathcal{C} \longrightarrow \mathcal{D}$ is to be conceived of as a left or a right adjoint. At first glance, neither assumptions (that $\mathcal{F}$ is a left adjoint or that it is a right adjoint) seem to be unreasonable, but both are too strong. Hence, one has to go. In Ibarra and Mormann (2006) we provide some arguments that the theoretization t has to be considered as the left adjoint, thereby resolving this unsettled situation.

4. *Prospects for a Dynamical Concept of Representation*

Authors such as van Fraassen or Giere have insisted in their recent work on a pragmatical conception of representation according to which the conditions representations have to satisfy conditions between different competing models and not those that have to do with their relation and the real world (van Fraassen, 2004; Giere, 2004). Nevertheless, in their accounts a hidden epistemological account survives that betrays certain foundational features. For instance, although Giere does not require the condition of objective similarity between the representation and the represented, nevertheless he insists on subjective similarities between the two components. This is close to Lakoff's account put forward two decades ago according to which representation requires the construction of a target domain in terms that adapt it to a source domain. Models do not represent by themselves and are not pictures of the world, but, according to Giere, it is their proposed usage that provides them with the role of representing a specific domain. Yet the quintessence of these accounts still seems to be to cope with problems of the foundations of knowledge considering the task of philosophy to consist in describing these elusive foundations. From this perspective it seems justified to maintain the thesis that the representational knowledge produced in this way remains neutral with respect to the world conceived as something "out there".

The conception of representation based on the dynamic of adjoint situations rejects the neutral character of the representational practices of science: knowledge is intervention in the world. As we argued in (Ibarra and Mormann 2006), representational practices possess an essentially intervening character as is evidenced in many scientific disciplines. For instance, the representational models in financial economics are not so much constructed as a means for knowing what a given system is but rather as a regulatory device of the system itself, i.e. as a constitutive element of the system designed for representation (Callon 1998). Another example is given by the role representations or models of molecules play in chemistry. Here, the task of representation is not to describe molecules "as they really are" but to design spaces of possibilities, in which transformations and interactions are modelled. A concrete case is provided by the methods of the so-called conformational analysis (cf. Leach 2001, chapter 9). Contrary perhaps to the layman's opinion, a chemical stuff is not simply "out there" such that it could be described once and for all by its chemical formula. Rather, the physical, chemical and biological properties of a molecule often depend on the 3-dimensional structures, or conformations, that it can adopt. Then, conformational analysis is the study of the possible conformations that a molecule can adopt and how they may influence on the molecule's properties. Thus, in a quite literal sense, conformational analysis constructs for every molecule a space of possible conformations. More precisely, "a key component of a conformational analysis is the conformational *search*, the objective of which is to identify the "preferred" conformations of a molecule..." (Leach, 2001: 457). Conformational search heavily depends upon on the interests, the technical means, and the mathematical methods available to the researcher. Thereby the conformational space is a domain that at the same time is explored as something given, but it is also an instrument to discover and design new molecules whose existence gives rise to new conformational spaces, which again may bring about still other new molecules, and so on. Thus the "geography" of a conformational space is not something fixed once and for all; rather it is something dynamic that leads to a kind of representational dialectics that up to now is only poorly understood by philosophy of science. Actually, using the concept of "dialectics" may not lead us very far, after all, it is a rather old-fashioned notion of 19th century's philosophy. The notion of adjoint situations may be a more modern conceptual device that could be useful here.

What is needed is a new concept that deals with the complex network of facts, means, and epistemological interests of the scientists. This network does not allow a neat separation of its components in, say, instruments that are used for producing representations, conventions that are adopted, and brute facts that are represented. This holds particularly for the role computers play in the constitution and evolution of such a network. They no longer play a role only as instruments for generating representations or simulated experiences but have become

themselves the object of representation. Galison expresses this transformation of the artificial world constituted by computers as a change "from computer as tool to computer-as-nature" (Galison 1996).

These experiences should reveal to us the characteristic aspects of many scientific practices, instead of leading to attempts to hide them. They should invite us to question the traditional dualistic theory of scientific knowledge that intends to bring together theory and the world of pre-existing objects, instead of considering these practices as anomalies or maverick practices that do not correspond to the standards of mainstream science. In sum, a theory of scientific representations should tackle the problem of identifying the conditions and circumstances under which the traditional picture of representation as a confrontation between world and theory becomes more or less acceptable. But this approach is obviously not equivalent with the stance that takes this confrontation for granted accepting it as a primitive element for any theory of scientific representation.

So what remains of the time-honored problematics of representation mentioned in the introduction of this paper? Certainly not the traditional question of what are the necessary conditions for representing an external reality, but rather the study of how the elements of interactive representations are constituted. In the first line, the construction of the spaces of possibilities of that constitution. These spaces are conceived dynamically as representational scenarios in which the concept of representation intervenes to render more accessible the adjoint situation of control and description. These functions of representation cannot be defined outside of this intervention. Secondly, what remains to be investigated further are problems of the combination and concatenation of representations in the framework of a combinatorial theory of representations that takes into account the plurality of representational forms in contemporary science (Knuuttila 2004).

5. *Concluding Remarks*

The aim of our paper was to show how scientific representations can represent the world if they are not pictures of the world but are related to it in a purely conventional manner. This task is not new and many authors have tackled it from a variety of different angles. In this paper we attempted to give this problem a new twist. For this purpose we have moved away from the objectivist concepts of representation which first intend to impose conditions on admissible representations thereby answering the first question of the traditional representationalist account as stated in the introduction of this paper, and then to formulate adequacy criteria, thereby answering to the second question of the traditional account, namely, what guarantees do we have which assure that represented and representing entities correspond to each other. This procedure is based on the presupposition that there is a world on which one can look from a neutral perspective. Our concept of representation intends to ground representation essentially on its intervening and interactive character. The world of scientific representations is a world representationally constituted that can be explored in a reflexive manner. The mathematical concept of adjoint situation offers a scheme for understanding the mechanisms of this interactive process of constitution. It allows to conceive the interest the concept of representation has for philosophy of science as residing in the fact that it is a complex process distributed in a plurality of combinations of representations of various types that form representational networks that constitute a plurality of ever new objects and related representations.

Thus, from our perspective, the emphasis on the functional virtue of representations consisting in that they offer the possibility of "surrogative reasoning", as Mundy called it some time ago, is misleading. This expression suggests that representational reasoning is somehow to be considered as a more or less poor substitute or "ersatz" of something else (Mundy, 1986; Swoyer, 1991). On the contrary, representational reasoning is a full-fledged reasoning in its own right. Representational reasoning is better understood in the process of combinations and concatenations of representations. But this is a complex problem that requires a full-fledged theory to deal with it.

Notes

1. One could even go back to Leibniz as one of the founding fathers of this account of representation as projection or homomorphic correspondence between a representing and a represented object (Leibniz 1678, 1687). Leibniz did not conceive "expression", i.e., representation, as an isomorphic relation in which for each element of the represented domain there was one in the representing medium corresponding to it but in terms of a weaker structural correspondence.

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SEPARABLE NON-INDIVIDUALS

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Abstract

We argue that in the informal semantics of quantum theories, we consider (even implicitly) the existence of collections of *non-individual* objects of some kind. But this assumption seems to be in disagreement with the idea of separability, for separability apparently entails individuality. In this paper we show that by a suitable change in the logico-mathematical basis, we have the grounds for saying that there may exist *separable* objects which do not have individuality. So we conclude that a form of *realism of non-individuals* is compatible with the standard formalism of quantum mechanics.

Keywords

< Quantum objects > < Non-individuality > < Separability >
< Quasi-sets > < Quantum ontology >

Introduction

The Bohr-Einstein dialogue is usually referred to as the most important scientific philosophical debate of the XXth century. As it is well known, the central issue was about the 'completeness' of quantum mechanics, defended by Bohr and criticized by Einstein. In short, Einstein claimed that there are "elements of reality" which can be measured, but cannot be accounted within the formalism of quantum mechanics. The famous EPR (Einstein-Podolski-Rosen) *Gedankenexperiment* was elaborated just for trying to show the incompleteness of quantum mechanics. Bohr reacted to this idea, and was taken by many as the winner of the debate (for a good description on this interesting history, see Ghirardi 2005: Chap.7).

Since the sixties, after Bell's theorem, which shows that in the quantum formalism we can derive certain inequalities which show that non-locality (see below) is a characteristic fact of quantum reality, the core of the problem came to be just an epistemological one, and gained

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