The aims of representative practices: Symmetry as a case-study

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By exploring the nature of scientific representative practices, I shall define a methodology that relates the use of symmetry to specific practical functions. In order to expound this approach, I shall investigate the role played by the conception of symmetry in representative practices from a philosophical and epistemological perspective. The paper proceeds as follows. In the first part, I introduce the reasons why our conception of representative practices should consider the aims and the objectives towards which they direct their interest. Secondly, by using symmetry as a case study, I try to show that philosophy can find fruitful pathways of interaction with sciences, as it is the case when it deals with the practical implications of the employment of symmetry in modeling. In the third section of the paper I shall refer to other examples that highlight the use of symmetry in scientific representative practices. I shall conclude with some remarks on the implications that this approach involves in epistemology, especially on our conception of objectivity and symmetry.

Keywords: representative practices, scientific representation, symmetry, models

Introduction

"The most important lesson that we have learned in this century is that the secret of nature is symmetry". With this statement D. Gross (1999, p. 57) echoed the method that Hermann Weyl advanced in *Symmetry* (1952). Weyl firmly believed that our *a priori* statements in physics are grounded on symmetry. And he was profoundly right in his claim. Nevertheless, the fact that symmetry can act as a canon in informing scientific theories and models, does not prove that the secret of nature is symmetry. It is widely acknowledged that there are different symmetries not only in physics, but also in other sciences. What we call "symmetry" hides a rich variety (we talk about symmetries in plural), a multiplicity of different possible operations that inform our current scientific theories and practices. For this specific reason symmetry is a suitable case study in order to reflect on scientific representative practices in general. But this is not the whole story. Weyl proposed to refer geometrical symmetry (bilateral and rotational symmetries) to certain operations that can be detected in both scientific and artistic representative practices: "Symmetry, as wide or as narrow as you may define its meaning, is one idea by which man through the ages has tried to comprehend and create order, beauty and perfection" (Weyl 1952, p. 5). The fact that we appeal to symmetry in different fields means that there are different representative practices that can employ analogous operations. If we take symmetry as being one of those operations unifying our methodology in different practices, we might discover that symmetry ceases to be a "secret of nature"; rather it appears as a **truth or a canon** of representative practices.

By illustrating the history of symmetry, it is possible to investigate a wide range of representative practices in different sciences, as well as different methodologies at stake in the use of symmetries. In dealing with the assessment of Weyl's approach, we specify the purposes and the aims underlying the choice of representing organic and inorganic processes by means of certain symmetries. Therefore the most natural question that enters into this picture concerns the status of symmetries and their *reification* in the world.

Do symmetries correspond to actual processes in nature? If we follow upon Gross, we are tempted to agree with this. However, Weyl also held a slightly different opinion. Symmetry (specifically in physics) does not correspond to the secret that nature is hiding; rather it appears to be one of the most powerful operations to order the interactions produced by processes that we are still trying to determine and clarify.[1] Nevertheless, it must be conceded that there is an analogy between the result of the interactions and the operations that we perform: this analogy rests on the ground of the operation of mapping the unity of the system under analysis according to an automorphism. However, it is not sufficient just to put certain constraints to the abovementioned question and restrict the possible kinds of symmetries that could find a correspondence in the actual world. There are elements in the scientific representative practices that allow ***the acquisition of the correspondence***, even if it is just in terms of approximation, for instance, between model-systems and target-systems, as well as between mathematical models and actual interactions. In order to assess the nature of these elements, we must look at what scientists do when using symmetries, namely at the aims that are at stake in scientific representative practices. The fruitfulness of this approach lies on the fact that in our specific case study we detect the unifying role of symmetries, according to certain practical functions, and we encompass phenomena into a system of principles and rules aiming at the unity of their representation. The point that must be highlighted here is that these principles and rules are chosen according to aims, objectives, and criteria of unification that fit the unity of the processes under analysis (we certainly find more than mere denotation in the engineering model of a bridge performed according to robustness criteria and in general in all performance-based models that aim at explaining phenomena such as failure, cracks, and so forth). In other words, a change of perspective is in order and the question we ask must be changed. Our conceptions of representation and correspondence in the current debate are to be re-shaped. This aspect is clarified in the next section and it is the starting point of our reflections.

Part I: Representation or representative practices?

Why should we talk about representative practices instead of representation? Why should our conception of representative practices consider the aims and the objectives towards which they direct their interest? These are questions that can be rightly asked at the very beginning of our reasoning.

The expression 'representative practices' might recall Sorrell's (2004) or Lynch and Woolgar's (1990) works, but the present perspective does not approach the subject sociologically or from a Peircean standpoint, even though it recognizes the framework of the social human activity that informs scientific or artistic representative practices. My claim is that the aims and the objectives pertaining to these practices that cannot be isolated from the use of certain model-systems and practical functions. These aims and objectives are part of the model-systems, because in informing them they allow the "acquisition of the correspondence" with a target system. This observation might be quite interesting, if applied to the current debate on scientific representation in the philosophy of science. The richness of this debate offered several answers to the constitution of model-systems informing scientific representation. Most of these answers, as far as I know, assume that this is a debate concerning the actuality, the possibility or the impossibility of a certain relation

[1] Weyl believed that there is a physical process in nature that determines the success of the use of symmetry in physics in terms of prediction (see Weyl, 1952, p. 25). The perspective according to which symmetry works as a sort of regulative principle that will be supplemented by a deterministic theory via the development of physics has been endorsed by Wigner (1967). For a complete overview on this topic see Brading and Castellani (2003).

of correspondence between a model and the world, or between a model-system and a target-system.[2]

An interesting example is offered by the "DDI" theory of representation of Hughes (1997), as underlined by Frigg (2010) also. Hughes identifies three elements pertaining scientific representation: elements of "denotation", "demonstration", and "interpretation". Hughes suggested that "if we examine a theoretical model with these three activities in mind, we shall achieve some insight into the kind of representation that it provides" (Hughes 1997, pp. 329; 335). The present perspective, as far as what I call "practical functions" of scientific representative practices are concerned, is close to Hughes' suggestion. The problem thus concerns how we represent something, namely what counts in the present approach are the activities and the functions that we associate to the aims of modeling phenomena.

Another claim underlying my analysis has been expounded by Callender and Cohen (2006), namely that while there is no special problem about scientific representation, there is a general question involving representation or, in our case, representative practice, be it scientific or artistic. However, as we shall see, Callender and Cohen still share the same view advanced by the prominent participants to the mainstream debate: they are still endorsing a view according to which representation is a relation or involves correspondence. Also they maintain that this is grounded on arbitrary stipulation, even if they rightly proposed not to treat representation *per se*.[3] On the contrary, I maintain that the distinction between art and science does not rely on the operations in themselves, rather on the way in which they are performed according to the aims we relate to them: geometrical symmetry, for instance, can be used in scientific practices and in art as well.[4] Albeit distinguished, art and sciences pertain to the same domain as being products of human social activities, and both scientists and artists interact, in very different ways, with the institutions.

Specifically, sciences are directed towards explicit or implicit aims, most of the time subordinated to the interests of political and economical institutions (both in the public and in the private sector). Nevertheless it would be far from a mere epistemological perspective to highlight the tasks linked to these interests. The question that should be raised here is the fact that due to this inevitable commitment to the social sphere and to the necessity of manipulation and control, scientific representative practices employ models that add something more to the model-descriptions.

As Frigg (2010) argued "model-descriptions usually only specify a handful of essential properties, but it is understood that the model-system has properties other than the ones mentioned in the description. Model-systems are interesting exactly because more is true of them than what the

[2] Within the debate on scientific representation, models received special attention. Giere claims that there is a "similarity" between a model and the world (Giere 1988, p. 81), depending on the intentions in designing and the use of the model performed by scientists (Giere 1992, pp. 122-123). Another claim is advanced by S. French who identifies the relationship between model and the real world as partial isomorphism (French 2002). Other introduced the normative aspects in dealing with representation (Morrison 2006) and pointed out that the representational and explanatory features of models are interconnected (Morrison and Morgan 1999).

[3] See Callender and Cohen (2006, p. 15): "In particular, we propose that the varied representational vehicles used in scientific settings (models, equations, toothpick constructions, drawings, etc.) represent their targets (the behavior of ideal gases, quantum state evolutions, bridges) by virtue of the mental states of their makers/users. For example, the drawing represents the bridge because the maker of the drawing stipulates that it does, and intends to activate in his audience (consumers of the representational vehicle, including possibly himself) the belief that it does". The weakness of this point is highlighted by Frigg (2010).

[4] But it is unlikely that an artist uses Maxwell's equations or tensor calculus in her representative practice. Why? The difference between these representative practices seems to concern different functions and the different aims and purposes that accompany the choice of the way in which we "represent" a phenomenon.

initial description specifies; no one would spend time studying model systems if all there was to know about them was the explicit content of the initial description. It is, for instance, true that the Newtonian model-system representing the solar system is stable and that the model-earth moves in an elliptic orbit; but none of this is part of the explicit content of the model-system's original specification".[5]

I add the observation here that this difference in instantiation between model-descriptions and model-systems depends on the aims attributed to the latter that are linked to concrete applications and to the aims of scientific representative practices in the human social organization (this is quite evident in the case of engineering practices or research in nanotechnology). It is undeniable that **there is a strong link between our models and scientific theories** that are produced by complex activities **and our social practices**, namely the fields and different activities in which we exert our knowledge, we acquire skills, we make experience and we set up the advancements for future development and research. Sciences are thus related to applications that transform the organization of our lives in the society.

Secondly, I would add that **different ways of representing phenomena** in sciences (but this holds in art as well) can **share common characteristics**, as the studies of Stegeman (1969), Callender and Craig (2006), and Frigg (2010) show. On the other hand, in my view, these representative practices also differ according to the **different aims** that are, so to speak, attached to the operations performed in their domains: the use of the model-system counts to mark this difference. This basic observation holds within the same scientific domain also. For instance, it is widely acknowledged that same phenomena can be 'represented', or better, modeled, in a different way by the engineer and the physicist (see section III example 4, when the engineering model is insufficient to fit the aims of the target-system, engineers appeal to physical model-systems).

But the same phenomenon can be described or explained on the ground of different models, depending on the chosen aims. For example, in the case of a bridge one can perform the analysis concerning lateral and vertical vibrations on the ground of a numerical model. Engineers can do it, by endorsing a prescriptive or a performance-based approach or both of them: the design can then proceed via models that are empirically informed, by taking into account human behavior interacting with a structure, or via the application of physical or biological models that show, as a result, the behavior analogous to the processes of interest. Scientists from different fields also propose different considerations of causal laws, for instance, because of the use of a scientific model that they chose to endorse. Same laws assume or lose relevance depending on the context in which they are used and produce a representation of the processes at stake directed towards certain aims (again see section III example 4, where from the virtual works principle descend two completely different models of physical systems and engineering models in the FEM, with inevitable consequences on the 'representation' of the target system).

Now, this kind of observations, however, could lead to the suspicion that philosophy cannot be helpful in reading these processes and practices. Even worse would be the case if we endorse relativism or dogmatic skepticism in face of these reflections.

I suggest an attempt to solve the difficulties at stake here and dissolve this suspicion. To restrict the domain of my enquiry, I shall focus on the specific case of the concept of scientific representation. This offers the chance to ask two main questions: 1. What are the possible

[5] Frigg (2010, p. 102).

ingredients of scientific reasoning and scientific representation? 2. What are the ways in which we produce and/or reproduce our scientific knowledge and representative practices?

I am interested in the second aspect rather than in the first attempt, which is related to a metaphysics and that I call 'the static approach' to scientific representation. We should start considering the idea of abandoning what I call a 'static' idea of representation. This is a philosophical point that is quite important in my view.

In what follows I propose the 'dynamical approach' to scientific representation, according to which principles and rules of certain processes are chosen according to aims, objectives, and criteria of unification that select and inform the unity (or a specific type of unity among many other possible) of the processes under analysis, even if they are just an approximation of the processes (be these processes the target-system or actual physical phenomena).

The current debate on scientific representation and idealization follows upon one of the most intricate philosophical questions, namely the possibility of any correspondence between thought and reality, and truth and reality. Even if the terms of the debate focus on data, models and scientific theories, the question of the possible relationship among them and its justification is far from being solved and is still drawn in terms of correspondence, no matter whether it is complete, incomplete or impossible (to these three terms we can refer the realist, antirealist and skeptic positions).

The history of philosophy might help us in this case. It is not by chance that for modern philosophy, from Descartes onwards, the term "representation" and its definition played a crucial role. By the end of the Seventeenth Century, representation had become a fundamental problem in epistemology, in natural philosophy, and in mathematics. In each of these fields, we can identify crucial topics that re-emerge in the subsequent development of philosophy of science and epistemology. In 1780s Immanuel Kant tried to undermine the problem, by establishing that representation is a 'general mark' in logical terms: it is so general and vague that the problem of a theory of knowledge should concentrate rather on the operations of the mind and forget about the correspondence-theory problem involving the mere concept of representation (*Vorstellung*, *repraesentatio*). Correspondence is a result of a complex process of manipulation, unification and acquisition, rather than an assumption, and the mere concept of representation does not explain the dynamics of this process.

However, philosophy seems unable to resist the temptation of reflecting upon the concept of representation *per se* and to assume its relation with a theory of correspondence (or non-correspondence). For instance, Frigg defines representation as follows: "Representation then is the relation between a model-system and its target-system".[6] He follows upon Callender and Cohen when he says that "It has been pointed out variously—and in my view correctly—that, in principle, anything can be a representation of anything else".[7]

So at present, if the reader allows this analogy, we are facing more or less the same problem faced at the end of the Eighteenth Century: the re-definition of the concept of representation and correspondence. The concept of representation is one of those concepts that we cannot easily abandon, because it offered a rich source for reflection and invested the crucial epistemological problem of correspondence that engaged philosophers in the last four hundred years.

However, if we change the conception of representation and correspondence underlying the studies on scientific representation, we might find that, even in the case of one of the most debated cases, the one of symmetry, our enquiry can throw a fresh light on it.

[6] Frigg (2010, p. 99).
[7] Frigg (2010, p. 99).

Part II: Symmetry in context

In this section I make use of symmetry as a case study in order to show how philosophy can fruitfully interact with sciences, especially when exploring the **implications** of the use of symmetries in different sciences. Weyl conceived of symmetry in the following terms:

> "As far as I can see, all a priori statements in physics have their origin in symmetry".[8]

According to Weyl, it is possible to identify symmetry with the basis of *a priori* statements in physics. What does it mean? I cannot concentrate here on Weyl's conception of *a priori*, but I suggest that he is using the term *a priori* in Kantian terms, namely, for him, the structure of our statement in physics lies on an *a priori* rule, symmetry, and this rule is not taken from experience, but it is mathematically constructed: it is an operation. Those who believe that models are set-theoretic structures identified symmetry with a property of the relation or the structure.[9] For them, models are structures, namely they are composed mathematical or set-theoretic entities in which what counts are the relations whose properties derive from reflexivity, transitivity, symmetry and so forth. I shall present now an alternative way of dealing with symmetry and scientific representation, alternative to French and Ladyman's at least.[10]

If we look at the practical implications of scientific representation, namely if we consider the dynamics at stake in scientific representative practices that employ different kinds of symmetries, we find that the aims are so to speak incorporated into the model system, which is not constituted by simple extensionally defined relations (see example B and section III example 4).[11] The second point that the structuralist approach misses is that symmetry (a part from its mathematical formulation confined within its definition of automorphism) is not a relation that can be referred to objects neither directly or indirectly without including properties that pertain to the specific system under analysis and that in some cases takes into account the material properties of the objects, but also human behavior (as it is in the case of the performance-based approach and risk analysis of structures in civil engineering). Moreover, as we shall see in this section, symmetry appears more as an operation at stake in scientific representative practices, and it does not exhaust the activity of modeling systems and processes. I shall start with examples of symmetries in geometrical objects

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[8] (Weyl, 1952 p. 126).

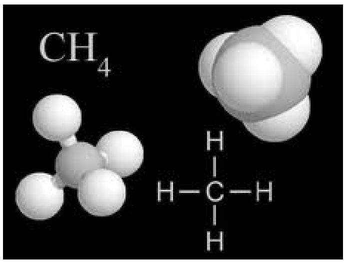
[9] Van Fraassen (1980), Da Costa and French (1990).

[10] I follow here Frigg´s criticism: "This definition of isomorphism brings a predicament to the fore: an isomorphism holds between two structures and not between a structure and a part of the world per se. In order to make sense of the notion that there is an isomorphism between a model-system and its target-system, we have to assume that the target exemplifies a particular structure. The problem is that this cannot be had without bringing nonstructural features into play". This point is clearly shown in the case of engineering model-systems, where even the material of the structure (i.e. wood, steal etc.) and the shape of the structural elements play a crucial role in modeling.

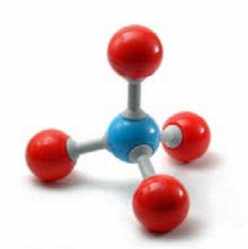
[11] I endorse here once again Frigg's criticism of this view: "For what follows it is important to be clear on what we mean by "individual" and "relation" in this context. To define the domain of a structure it does not matter what the individuals are—they may be whatever. The only thing that matters from a structural point of view is that there are so and so many of them. Or to put it another way, all we need is dummies or placeholders. Relations are understood in a similarly "deflationary" way. It is not important what the relation "in itself" is; all that matters is between which objects it holds. For this reason, a relation is specified purely extensionally, that is, as class of ordered *n*-tuples and the relation is assumed to be nothing over and above this class of ordered tuples. Thus understood, relations have no properties other than those that derive from this extensional characterization, such as transitivity, reflexivity, symmetry, etc. This leaves us with a notion of structure containing dummy-objects between which purely extensionally defined relations hold".

and their possible use in chemistry. These three examples are taken from Gerard ‘t Hooft’s lectures held at the University of Utrecht in 2008.[12]

A- Examples of symmetries in geometrical objects are given by symmetries of transformations as rotations and reflections that leave geometric objects **invariant**. Symmetries of geometric objects are relevant in sciences, as shown in the case of a molecule with tetrahedrical symmetry. The CH_4 (methane molecule) has the form of a tetrahedron and the symmetry of the molecule usually determines some of the physical and chemical properties of the substance (for example the band structure that it shows in Infrared and Raman spectroscopy).[13]



We infer that if a molecule possesses inversion symmetry (there is a point $\vec{p}$ such that the molecule is invariant under $\vec{x} \mapsto 2\vec{p} - \vec{x}$), this cannot have an electric dipole moment. In this case we define invariance and an actual property, by acquiring a correspondence between what we can find in nature and the rules of symmetry that we follow in order to be oriented in practical experience. The aim associated with this practical function is to manipulate and to classify physical bodies for further tasks and applications.



B- Transformations of space and time that leave the equations of motion invariant constitute another example that is extremely helpful to show that we incorporate aims in scientific representative practices. For Newtonian physics these symmetries are the transformations forming the Galilei group, which is a 10 dimensional Lie Group:

1) $\vec{x} \mapsto \vec{x} + \vec{x}_0$ spatial translations

2) $t \mapsto t + t_0$t time translations

3) $\vec{x} \mapsto \vec{x} + \vec{v}_0 t$ relative movement at constant velocity

4) $\vec{x} \mapsto R_0 \vec{x}$ spatial rotations

These symmetries are extremely relevant in physics, because we associate the aim of **finding** conserved quantities to the symmetries of the equations of motion, according to a practical function of prediction. For relativistic physics the equations are invariant under *Lorentz transformations* (which also are a 10 dimensional Lie Group). The translations and rotations act the same way as in the Galilei group; however, the transformations that relate reference systems that are moving with constant velocity relative to each other act differently. Consider the equation:

$$\Box\, \phi(t,x,y,z) \equiv \left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z^2} \right)\phi(t,x,y,z) = 0$$

[12] http://www.phys.uu.nl/~sahlmann/teaching/lecture%20notes/discrete%20groups%20lecture%20notes.pdf.
[13] Coates (2000, pp. 10815–10837).

By assuming that Lorentz invariance is a fundamental symmetry of nature, then the form that the equations of motion for the various matter fields and forces can take is severely **restricted**. The practical function of prediction operates here in synergy with the practical function of restriction (see example C). Furthermore, we can detect the practical function of prediction, by considering *Noether's Theorem*, which establishes that if in a theory there is a continuous *n*-parameter family of symmetries, then there are *n* conserved quantities. If the equations of motion for a field are invariant under time translations, there is a conserved energy density for this field. The scientific representative practice at stake here is one of the most relevant for studies in physics and is directly linked to the practical function of **prediction** that we attribute to scientific theories and models.

C- Gauge symmetries that leave local equations of motion invariant are **restrictive** in terms of the equations of motion that they allow. Gauge symmetry plays a crucial role in the foundation of the Standard Model, given that the fundamental interactions (electromagnetic, weak and strong) are symmetric *under* a certain gauge symmetry: gauge symmetry dictates the form of the interactions and in doing so it allows to perform the practical function of **restricting** the equation of motion to be used in a certain scientific theory and in model-systems. Also it allows us to construct a system of interaction to classify phenomena at high energy scales.

Before going on to Part III, it must be noticed that in scientific representative practices three practical functions emerge from these examples:

In case A we have the dominance of the function of **invariance**: we generally attribute objectivity to this function in order to **define properties of the processes under analysis**, **classify** and **manipulate** them for further aims.[14]

In case B we have the dominance of the function of **prediction**: symmetry is of a fundamental import in order to 1) **find conserved quantities of a system** independently from its degree of complexity, and 2) **incorporate phenomena** into a system via implemented classification (see case C).

In case C we have the dominance of the practical function of **restriction**: symmetry allows the **selection of necessary rules** and principles to be used for further tasks within the framework of a specific theory and at the same time it informs its systematic and unified character.

For each of these functions there are aims directly linked to the use of symmetry in different sciences. The aims I illustrated accompany our scientific representation in practice and every scientific enterprise. These consist in:

-Definition of properties
-Classification
-Manipulation
-Finding of conserved quantities
-Selection of necessary rules

[14] Note that symmetry is not to be completely identified with invariance as pointed out by Roman (2004, p. 6).

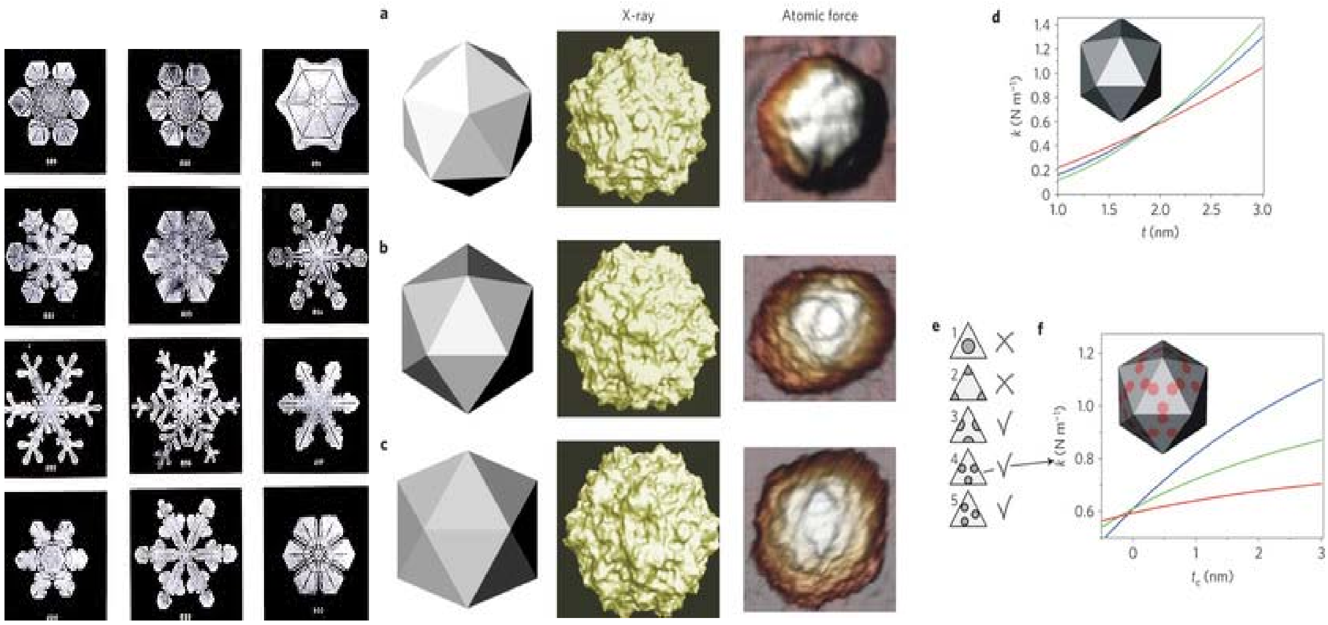
The next step shows that these aims are not at all arbitrary, but respond to necessary tasks of scientific practices that profoundly influence the organization of our life once they are applied to specific fields.

Part III: Symmetry and scientific representative practices

In this last section on symmetry, I shall refer to examples that highlight the employment of symmetries in different fields as aim-directed scientific representative practices. The most interesting case in terms of applicability of symmetries concerns geometrical symmetries of rotations, translations and reflections directed towards invariance, classification and prediction. The best known examples of these symmetries are taken from crystallography, chemistry, and biology. The last example concerns engineering models.

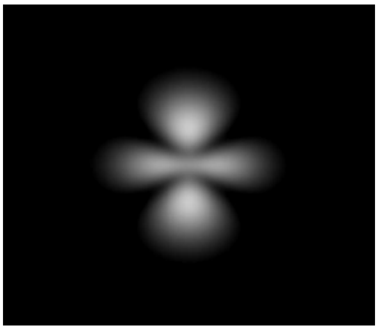
1. Snowflakes and Crystals

In this first example, the practical function of **classification** is clearly displayed by using geometrical symmetry in modeling snowflakes and crystals. The symmetry is “injected” in physical bodies to easily **compare** them with other samples. However, as shown in the X-ray and atomic force diagrams, geometrical symmetry allows an approximation, not a pure correspondence between the model and the physical object. This idealization is directed towards aims of comparison, classification and intervention.



2. Lie Groups – Hydrogen Atom

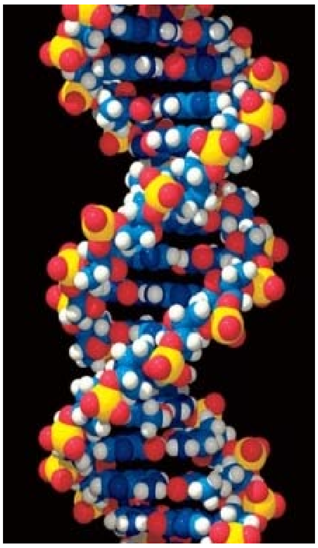
In the specific case of the hydrogen atom, scientists insert operators to render it symmetrical in both the relativistic and non-relativistic case for the purpose of prediction and explanation. This aspect is

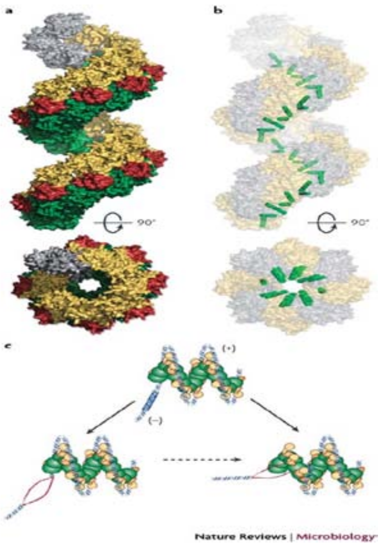


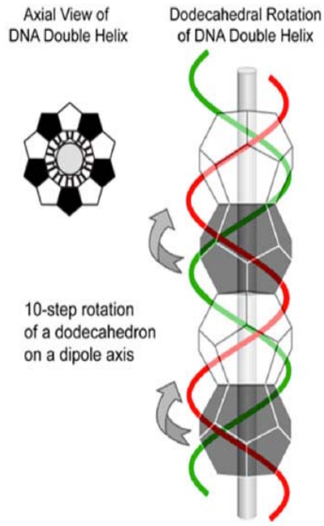
clearly pointed out by S. Singer.[15] Her analysis focuses on **how** to make **predictions** about the **numbers of each kind of basic state of a quantum system** from only two ingredients: the symmetry and linear model of quantum mechanics. This method has wide applications in crystallography, atomic structure, classification of manifolds with symmetry and other fields. Also, as shown by S. J. Weinberg (2011), it is possible to generate SO(4) symmetry from Lie algebra in the methods for analyzing the hydrogen atom. Through the use of dynamical symmetry scientists provided a new approach to the "accidental degeneracy" of the hydrogen atoms energy levels and explained it. Further applications of this model in physics can be found in Vibron Model Description of molecules, the Interacting Boson Model of the Atomic Nucleus, the SU(3) classification of hadrons, and the Bose–Einstein condensates of spinor and tensor bosons. The hydrogen atom model inspires current studies in genetics and biology, as we shall see in the next example.

3. The DNA Structure (Helical Symmetry)

The reason why we use helical symmetry in modeling DNA structure has obvious practical implications in terms of description of the processes of its replication in order to intervene and manipulate them. As the pictures show, we can perform dodecahedral rotation or privilege the axial view of DNA double helix, according to the aim of intervening on it and easily identify the processes of a certain interest in simulations and test. As R. Sinden (1994) argued, two-dimensional and three-dimensional nuclear magnetic resonance (NMR) data of DNA in solution provided three-dimensional coordinates for the position of individual atoms in DNA, with the result that the picture that emerges is one of an extremely variable helical structure, not at all uniform and monotonous. Furthermore, the secondary structure of DNA can assume myriad alternative or non-B-DNA forms (which are the most common models used since 1960s and derived from X-ray diffraction analysis).[16]







[15] Singer (2005, pp. 283-296).
[16] Sinden (1994, pp. 3; 32).

The classical model is *de facto* insufficient when the evolution of the genetic code is considered. In genetics, scientists prefer to employ a pseudo-orthogonal (Lorentz like) symmetry in stochastic modeling, in order to 'represent' a genetic network. In this way, models of gene expression are linked to the practical function of **prediction** of processes involved in the secondary structure of DNA. This practical function was weakened in the classical model. Rather, as I claimed in the previous example, the study of the energy levels of hydrogen atoms played a crucial role in developing models ***analogically*** applied to genetics. Also scientists may refer to an algebraic approach in modeling the evolution of the genetic code: a current code is generated by a dynamical symmetry breaking process, starting out from an initial state of complete symmetry and ending in the observed final state of low symmetry. In both cases, symmetry plays a decisive role: in the first case, it is a characteristic (invariant) feature of the dynamics of the gene switch and its decay to equilibrium, whereas in the second, it provides the guidelines for the evolution of the coding.[17] Also it is possible to identify the three practical functions (invariance, prediction, and restriction) associated to the use of symmetry in scientific representative practices. The following passage clarifies these aspects and we can detect in the scientists' words the operations they performed, according to the practical functions and the aims associated to their practice:

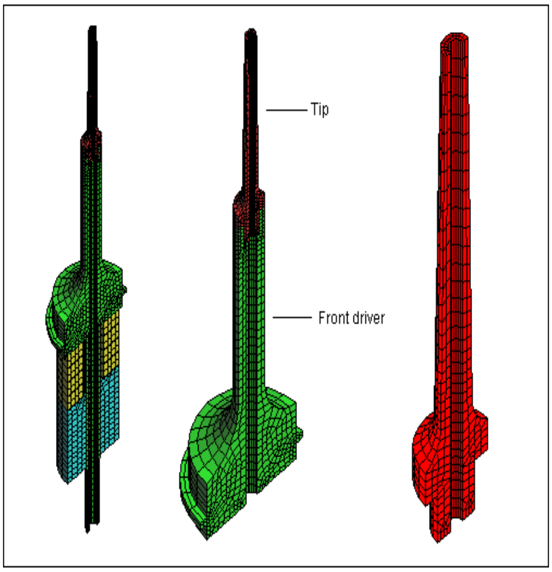
"The notion of degeneracy is profoundly related to that of symmetry. Degeneracy means **invariance**; in the present case, it means that the codon to amino acid assignment is invariant under the replacement of codons by synonymous ones. And invariance means symmetry, in the sense that one can build transformation groups that keep invariant certain properties. This kind of connection between symmetry and invariance can be seen in the spectrum of the hydrogen atom: this is a system with an obvious rotational symmetry, implying that states with the same azimuthal angular momentum quantum number m **will have** the same energy. But symmetries may be much less obvious than in this case; they may be hidden! And there are many examples where the spectrum of a molecule or atom is a testimony of some hidden symmetry. Thus if we look at the genetic code from this point of view, ***as if*** **it were some kind of spectrum**, we face a straightforward question: is the degeneracy pattern of the code the expression of some hidden symmetry? This promptly suggested performing what we may call '**the search for** symmetries in the genetic code'. […] **Lie group theory provides a well-developed mathematical machinery for modelling symmetry in biological systems**. **It provides not only a quantitative framework but also leads to biological insights about the processes that are modelled**, as shown by the examples presented in this review. ***In the stochastic model for a two-state gene, symmetry has practical implications***: the eigenvalue of the diagonal operator characterises the dynamics of the gene switch and the affinity between the regulatory protein and the gene operator site, whereas the non-diagonal operators connect the probability distributions of the two states. In addition, noise analysis leads to the conclusion that fast switching genes give rise to Poissonian distributions whereas slowly switching genes have broader or bi-peaked distributions. **In the algebraic model for the evolution of the genetic code, possible pathways for this evolution arise naturally, but are strongly restricted. The picture of evolution by a stepwise incorporation of new amino acids *fits perfectly* with that of dynamical symmetry breaking**. The Klein symmetry that has remained preserved can serve as an **underlying principle** that has conducted the evolution of the standard code as well as that of non-standard codes. In the modelling of gene networks, group theoretical tools can be **useful for the search for a composition rule** between two or more genes. Another feature is the possibility to model single genes that present more than two levels of regulation. **The construction of a dynamical system for the evolution of the genetic code is also a possible future application of group theoretical methods in biology**".[18]

[17] See Ramos, Innocentini, Forger, Hornos (2010).
[18] Ramos, Innocentini, Forger, Homos (2010).

As it appears from this passage, we cannot detach a model system from its specific use. Also as I have previously pointed out, what we call "correspondence" in representing phenomena is nothing else but a process of fitting aims of scientific representative practices. In view of these aims scientists analogically construct the unity of the processes under analysis. This definition seems to be valid for model systems both referred to target-systems and phenomena.

4. Symmetry in Engineering Modeling: FEM

I shall introduce now symmetry used in the **Finite element method** (FEM) in order to show the limitations of the structuralist account of models. The FEM is a technique originally developed for numerical solution of complex problems in structural mechanics, and it remains the method of choice for complex systems. In the FEM, the structural system is modeled by a set of **finite elements** connected at points (or nodes). **Elements may have physical properties, such as thickness, coefficient of thermal expansion, density, Young's modulus, shear modulus and Poisson's ratio. It is also possible to model straight or curved one-dimensional elements with physical properties such as axial, bending, and torsional stiffness**. In engineering the use of this kind of elements aims at modeling the behavior of cables, braces, trusses, beams, stiffeners, grids and frames that in turn can be parts of more complex structures. The elements are positioned at the centroidal axis of the actual members. The picture shows that via axial symmetry only half of this resonator has been modeled. By reducing the number of elements the analysis time is significantly reduced, as well as the costs. There is clearly a utilitarian function attributed to geometrical symmetry here. Indeed, the introduction of FEM has substantially decreased the time to take products to the production line. Through improved initial prototype designs using FEM testing and development have been accelerated and productivity increased.



But what is really intriguing for the present perspective is that certain elements properties in the FEM must be part of or coincide with the model-systems: this represents a challenge to French's account of models as structures. If we have to account, for instance, for gusset plates buckling we appeal to the FEM. Now, in French's view, the numerical model would be isomorphically mapped into the FEM. But in the FEM there is more than the mathematical model, which appears to be rather the basis for the prediction of the behavior of the element which is modeled in the FEM. Furthermore, the mathematical model does not entail the exact relationships of displacement modeled to account for the actual buckling of a gusset plate (it must include, for instance, thermal coefficients depending on the material and the shape of the gusset plate). In the FEM the elements properties determine the models, for example, when two-dimensional elements have to capture membrane action (plane stress, plane strain) and/or bending action (plates and shells). They can also have a variety of shapes (flat or curved triangles and quadrilaterals). Nodes are usually placed at the element corners and additional nodes can be placed along the element edges or even inside the element. The elements are positioned at the mid-surface of the **actual layer thickness, and to do so, one does not rely on the mathematical model only**. This is the case also for torus-shaped elements used to solve axis-symmetric problems, such as thin, thick plates, shells, and solids that may have cross-sections similar to the previously described types. Now, the behavior of nodes is modeled according to nodal (vector) displacements or degrees of freedom, which **may** include translations, rotations, and for special applications, higher order derivatives of displacements. But these model-systems include more than these relations and ‘structures’.

Model-systems including these elements follow upon symmetry or asymmetry conditions that are exploited in order to **restrict** the size of the domain. In this way, displacement compatibility is ensured at the nodes, and preferably, along the element edges as well, particularly when adjacent elements are of different **types, material or thickness**. Compatibility of displacements of many nodes can usually be imposed via **constraint relations** imposed to nodes on symmetry axes, and when it is not feasible, a physical model that imposes the constraints may be used instead. In the model-systems the elements’ behaviors **capture** the dominant **actions** of the actual system, by adding something more (elements’ shape, empirical constraints, and so forth) to the mathematical model.

FEM has radically improved both the standard of engineering designs and the methodology of the design process in many applications. For example, in spice-compatible circuits and system simulators, it can be used a combination of analytic and numerical approaches in the FEM that generates other models to consider more complicated effects. In “Behavioural modeling for heterogeneous systems based on FEM descriptions”, J. Haase, S. Reitz, and P. Schwarz have shown that model-description are incorporated into model-systems to fit and predict the behavior of a certain structure. The interaction of these models into one model-system is determined by the laws at stake (in the specific case, a generalization of Kirchhoff’s Current Law) that regulate the unity of the process under analysis. **The method of incorporation of two or more model-descriptions into one model-system** allows the usage of analytical FEM formulas for the construction of behavioral models, to derive behavioral models with fixed numerical values for components from FEM descriptions, and the implementation of models in different languages (MAST, HDL-A, VHDL-AMS). This methodology employed in scientific representative practices, although is not immediately related to symmetry, encompasses it in the FEM. Moreover, it confirms that the use of a model (be it a model-description or a model-system) makes the difference in scientific practices for the definition of the models-system itself that should account for complex actual processes.

Conclusion

Why and how do we use symmetry in representing? It appears that we use symmetries in our scientific practices and we perform them according to practical functions of invariance, prediction, and restriction in order to control and further manipulate models and their associated phenomena. We intervene and manipulate certain processes according to an order that is dictated and controlled by functions, operators etc., so that we can predict part of the behavior of a structure under certain transformations that leave it invariant. But given that models include the operations of our scientific representative practices, they also include the practical functions and the associated aims that inform the model-systems. It does not mean, however, that a physical object is the product of a mere arbitrary construction, nor that model-systems are just structures. It is rather evident that when we adopt certain representative practices in sciences, particularly by using symmetry (or asymmetry) in modeling, we are pursuing certain specific aims depending on the functions of

invariance,[19] prediction and restriction. Representing in science is never unrelated to aims and sciences, especially in their applications and problem solving contexts reveal this crucial aspect.
For this reason I cannot agree with Frigg on that “the intrinsic nature of a model-system does not depend on whether or not it is so used: representation is extrinsic to the medium doing the representing”.[20] We have seen how the dynamical approach to the question of scientific representation allows us to deal with crucial elements that are disregarded by current interpretations.

From the present perspective, in the case of symmetry there is something more to be added to our conception of representation, especially scientific representation. The latter cannot be read in terms of correspondence or relation simply. The mere use of the term ‘representation’ is ambiguous, because it prevents us from seeing the dynamics underlying scientific processes and from explaining the fact that we use specific scientific tools to predict and anticipate phenomena, whose unitary process is incorporated and captured by the model-systems.
The concept of representative practices is an ideal substitute for the concept of scientific representation, because it focuses on the way in which we order and restrict data, laws and phenomena, not only in a descriptive, but also in an explanatory way. A desirable account of scientific representative practices looks at the purposes that we may inject into models via the performance of practical functions. In the specific context of this paper, I have shown that to expound the reasons why we use symmetries in sciences means to deal with a certain conception of objectivity as invariance (see Part II, example A), and, according to the proposed view, the question of objectivity can be inserted in the context of a dynamical approach to representative practices. Objectivity is linked to practical functions and aims of scientific representative practices: the more the results of a model-system fit the aims at stake (such as explaining the failure of a bridge or the replication of DNA by comparing two double-helix structures), the more the operations and functions they are attached to acquire objectivity. Objectivity ceases to be read in terms of correspondence and becomes a process that includes the operations we perform and their aims.

The concept of representative practices certainly tells us that we look at the fixed properties, primary properties as relations of invariance of/in a certain system, but also that this is not the whole story. If we were happy with this perspective only, we would not be able to identify the vast range of functions of symmetry in sciences. On the contrary, as I tried to show, it is with the identification of other crucial practical functions and the aims that we associate to models that we can give a more satisfactory account of scientific practices,[21] and then throw a fresh light on the use of symmetries in sciences. Conclusively, scientific representative practices (that refer to something more than a mere mapping or performance of isomorphism) are conceived as of aim-directed processes of ordering phenomena or laws according to a chosen rule that must respond at least to one of the three abovementioned functions: invariance, prediction, and restriction. Although it is far

[19] Though, as I tried to show, there is not a perfect correspondence between symmetry and invariance.
[20] Frigg (2010, p. 99). Frigg’s perspective is closer to what I called the ‘static approach’ to scientific representation, dealing with the “intrinsic nature” of model-systems and the ingredients of scientific representation. The disagreement does not concern his arguments, which I find consistent with his perspective, but rather it is due to the different project I propose.
[21] Furthermore to investigate these practices from a dynamical perspective means to analyze the relationship between scientific and artistic representative practices also, because they depend on the same ground: **human social activity**. In scientific representative practices we relate the operation of symmetries to images, to visualization, qualitative and material properties, as it is in the case of lattices, molecule models, snowflakes etc. Now, these ‘representations’ turn out to be beautiful as well. As Weyl remarked, we represent something for scientific purposes, but it turns out to be part of another representative approach, or better representative practice, which pertains to art. We have still to explain why and how this is possible.

from being complete, the proposed approach to scientific representative practices is different from other alternatives because it ties together the practical functions and the aims associated to the processes of acquisition of the correspondence between model-descriptions, model-systems, target-systems and the actual processes or structures. Further discussion concerns the ground of the agreement on the use of certain models and the interpretations of different results descending from scientific practices. And more importantly, the present approach perhaps entails the possibility of re-defining or abandoning the concept of correspondence in the current debate on scientific representation. But this is another question that deserves further discussion.

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