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The Pragmatics of Scientific Representation

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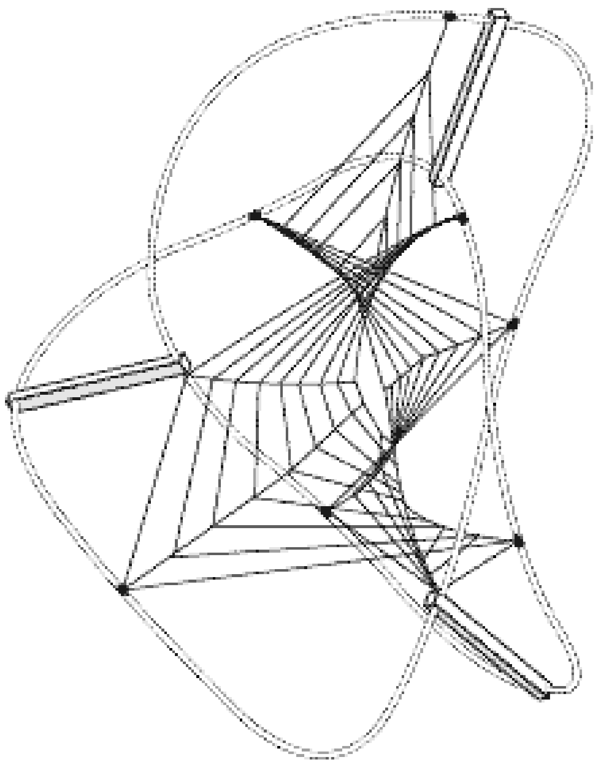

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THE PRAGMATICS OF SCIENTIFIC REPRESENTATION[1]

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Abstract:

This paper is divided in two parts. In part I, I argue against two attempts to naturalise the notion of scientific representation, by reducing it to isomorphism and similarity. I distinguish between the means and the constituents of representation, and I argue that isomorphism and similarity are common (although not universal) *means* of representation; but that they are not *constituents* of scientific representation. I look at the prospects for weakened versions of these theories, and I argue that only those that abandon the aim to naturalise scientific representation are likely to be successful. In part II of the paper, I present a deflationary conception of scientific representation, which minimally characterises it by means of two necessary conditions: representation is essentially intentional and it has the capacity to allow surrogate reasoning and inference. I then defend this conception by showing that it successfully meets the objections and difficulties that make its competitors, such as isomorphism and similarity, untenable. In addition the inferential conception explains the success of various means of representation in their appropriate domains, and it sheds light on the truth and accuracy of scientific representations.

[1] Part I has been submitted to *International Studies in the Philosophy of Science*; a shortened version of Part II is forthcoming in *Philosophy of Science Proceedings*.
[2] This paper is the result of a five-year long project, and it would carry a long list of individual acknowledgements. Bas Van Fraassen and Ronald Giere stand out for useful comments and suggestions; and Arthur Fine stands out for his encouragement and confidence in the project from its very beginning. I would like to thank all those who offered helpful comments and suggestions when I delivered portions of the paper at Northwestern University (1998), Universities of Chicago (1998), Bradford (2000), Leeds (2000), Exeter (2002), California at San Diego (2002), Damstaadt Technical University (2002), Santiago de Compostela (2002); and at the International Conferences at Pavia (1998), New Mexico State University (2001 and 2002), Dubrovnik (2002); the Italian Society for Analytical Philosophy conference in Bergamo (2002), and the Philosophy of Science Association biennial conference in Milwaukee (2002). Thanks to my students at the III Summer School in Theory of Knowledge, Madralin (2001), and to its organisers, particularly Ryszard Wojcicki, for inviting me. I also thank the Leverhulme Trust for awarding me a research fellowship without which I would not have found the time and energy to write it all down.

Contents:

PART I: HOW NOT TO NATURALISE SCIENTIFIC REPRESENTATION

1. Theories of Scientific Representation.

Many philosophers of science would agree that a primary aim of science is to represent the world.[3] What those philosophers understand by "represent" is however a lot less clear. No account of representation in science is well-established. Perhaps this is not surprising. Consider the following four very different examples of successful scientific representation, drawn from engineering and mathematical physics respectively: a toy model of a bridge; an engineer's plan for a bridge, such as the Forth Rail Bridge[4]; the billiard ball model of gases[5]; and the quantum state diffusion equation for a particle subject to a localization measurement.[6] What could there be in common between such disparate models that allows them to represent?

I choose these examples mainly because they illustrate the range and variety of representational devices in science. In these examples we may usefully distinguish

[3] For instance Cartwright (2000), Giere (1988, 2000), Friedman (1982, chapter VI), Kitcher (1983), Morrison (2001, chapter II), Morrison and Morgan (1999), van Fraassen (1981, 1987). A well-known dissenter is Ian Hacking (1983).
[4] An example carefully documented by Michael Baxandall (1985, chapter 1).
[5] For a philosophical treatment, see Hesse, 1967.
[6] See I. Percival (1999), pp. 49-51.

between the *source* and the *target* of the representation. Roughly, the source is the vehicle of the representation, the target is its object. In the first two examples the source is a concrete physical object and so is the target. In the third example we may describe the source as a physical system and the target as a state of a nature. In the fourth example the target is a physical phenomenon and the source a mathematical entity, an equation. In all these cases A is the source and B is the target because "A represents B" is true. There are of course many other kinds of representational media in science. The sources of scientific representations may be concrete physical objects, systems, models, diagrams, images or equations; and similarly for possible targets. The only thing that these types of objects have in common is that they all putatively include real entities in the world.

I take it that a *substantive* theory of scientific representation ought to provide us with necessary and sufficient conditions for a source to represent a target. It is natural to expect these conditions to agree with our underlying intuitions about ordinary representation in general; but we should not necessarily require the conditions of scientific representation to be identical to those for ordinary representation. Neither will I require that a theory of scientific representation be able to explain the human capacity to generate representations, or mental images of the world.[7]

In addition, a good theory may provide us with insight into some of the features that are normally associated with scientific representations such as accuracy, reliability, truth, empirical adequacy, explanatory power; but again I will not assume that this is a requirement. In other words, I will not require a theory of representation to mark or explain the distinction between accurate and inaccurate representation, or between reliable and unreliable one, but merely between something that is a representation and something that isn't.[8] This presupposes a distinction between the conditions for *x* to be a representation of *y*, and the conditions for *x* to be an <u>accurate</u> representation of *y*. Both are interesting issues, but they must addressed and resolved separately. Science often succeeds at constructing representations of phenomena, but it rarely succeeds at constructing completely accurate ones. On discovering particular inaccuracies in the representation we are very rarely inclined to withdraw the claim that it is *a* representation. Thus a graph can be a more or less accurate representation of a bridge, and a quantum state diffusion equation can be a more or less accurate representation of a particular instance of localisation. In this paper I have little to say about what makes one representation more accurate than another.[9]

In this paper I critically discuss two proposals for a substantive theory of scientific representation along these lines. The intuition underlying these theories may at first appear natural and pervasive, but I will argue that on careful analysis it must be resisted. The intuition is that a source A is a representation of a target B if and only if A, or some of its parts or properties, constitute a mirror image of B, or some of its parts or properties.

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[7] This is the aim, for example, of Woodfield (1991).

[8] I do so in part for argumentative reasons. I want to claim that there can be no substantive theory of the constituents of representation. My argument would be weaker and less interesting the stronger the independent conditions on a theory of representation.

[9] The inferential conception that I develop in the second part of this paper does indeed shed some light on the accuracy, reliability and explanatory power of representations.

A and B are entities occurring in the world described by science, so a thorough scientific investigation of all the facts about A and B and their relation should thus suffice to settle the matter.

This is perhaps best summarised by means of a slogan: "scientific representation is a relation that occurs in fact between entities in the world which can be studied by science". More specifically the intuition is that for A to scientifically represent B, it must first be the case that A and B and their properties fall under the scope of science, and second that A's and B's properties are in fact related in accordance with some law established within science itself. The relation of representation is factual and does not necessarily involve judgements on the part of agents. This naturalistic conception of representation has the virtue of guaranteeing the objectivity of scientific representation which, unlike linguistic representation perhaps, is certainly not a matter of arbitrary stipulation by an agent. On naturalistic conceptions, whether representation obtains depends on the way the world is entirely, and it does not in any way answer to the personal purposes, views or interests of the inquirer. However, other non-naturalistic conceptions may guarantee the appropriate level of objectivity of scientific representations as well. In this paper I argue that the two main naturalistic alternatives are mistaken, thus pointing to the conclusion that no substantive scientific theory of scientific representation will succeed.

2. Representation Naturalised: Similarity and Isomorphism.

What sort of relation must hold between A and B for A to represent B? For instance, what relation must hold between the graph of a bridge, and the bridge it represents? It is obvious that not any arbitrary relation between A and B will do: for there are all sorts of relations that obtain between A (e.g. the graph) and B (e.g. the bridge), which are irrelevant to the representational relation itself – such as "being an artifact", or "being at least 10 cm. long". The success of the project of naturalizing representation is crucially dependent upon finding a suitable type of relation that can fill in this role. For the theory of representation to be <u>substantive</u> in my sense it is required that this relation obtains universally between the source and the target, in all instances of successful scientific representation.

Two accounts have been available in the literature for some time: similarity and isomorphism. Ronald Giere (1988, 2000) has defended the importance of similarity for representation, which has also been stressed for instance by Aronson, Harré and Way (1993). Bas van Fraassen (1991, 1994) has concentrated on the virtues of isomorphism; and other writers in the structuralist tradition, including most prominently Brent Mundy (1986), have appealed to weakened versions of isomorphism. [10]

[10] I am not suggesting that Giere and Van Fraassen have defended the conditions that I refer to as [iso] and [sim]. But they are often understood this way. My paper can be seen as articulating clearly what Giere and Van Fraassen can be taken to claim, and what they can't. I share with both Giere and Van Fraassen an emphasis on the pragmatic dimension of representation. Van Fraassen in particular is explicit about the intentional character of representation in general, and specifically of scientific representation (1992, 1994, 1999).

We may enunciate the corresponding theories as follows:

The *similarity conception of representation* [sim]: A represents B if and only if A is similar to B.

Similarity is a generalisation of resemblance. Two objects resemble each other if there is a significant similarity between their visual appearance. [sim] does not assert that resemblance is a necessary and sufficient condition for representation; it is a weaker condition, which neither requires nor includes similarities in visual appearance, or a threshold "significant" amount of similarity. The following is typically assumed: A and B are similar if and only if they share a subset of their properties. In accordance with this *identity-based theory* similarity is reflexive (A is maximally similar to itself), and symmetric (if A is similar to B, on account of sharing properties $p_1, p_2, \ldots p_n$, then B is similar to A on the same grounds); but non-transitive (A may share p_1 with B, and B may share p_2 with C, without A and C sharing any property – other than the property of sharing a property with B!).

The *isomorphism conception of representation* [iso]: A represents B if and only if the structure exemplified by A is isomorphic to the structure exemplified by B.

Isomorphism is only well defined as a mathematical relation between extensional structures. Hence the above definition presupposes that any two objects that stand in a representational relation exemplify isomorphic structures. The notion of structure-exemplification turns out to be ridden with difficulties; but the definition has the virtue that it makes sense of object-to-object representation outside pure mathematics. The claim that two physical objects A and B are isomorphic is then short-hand for the claim that the extensional structures that A and B exemplify are isomorphic. In what follows "A" will indistinguishably denote the source and the structure that it exemplifies, and "B" will denote the target and the structure that it exemplifies. Isomorphism then demands that there be a one-to-one function that maps all the elements in the domain of one structure onto the elements in the other structure's domain and vice-versa, while preserving the relations defined in each structure. Hence A and B must possess the same cardinality. More precisely, suppose that $A = < D, P^n_j>$ and $B = < E, T^n_j >$; where D, E are the domains of objects in each structure and P^n_j and T^n_j are the n-place relations defined in the structure. A and B are isomorphic if and only if there is a one-to-one and onto mapping $f: D \rightarrow E$, such that for any n-tuple $(x_1,\ldots, x_n) \in D$: $P^n_j [x_1,\ldots, x_n]$ only if $T^n_j [f(x_1),\ldots, f(x_n)]$; and for any n-tuple $(y_1,\ldots, y_n) \in E$: $T^n_j [y_1,\ldots, y_n]$ only if $P^n_j [f^{-1}(y_1),\ldots, f^{-1}(y_n)]$. In other words, an isomorphism is a relation preserving mapping between the domains of two extensional structures, and its existence proves that the *relational framework* of the structures is the same.[11]

[11] Isomorphism is sometimes said to preserve, or amount to, "structural identity". Such terminology is misleading since the isomorphic structures A and B are distinct: they have different objects in their domains. It is rather the "super-structure" of the logical properties of the relations in isomorphic structures that is identical. For that reason I prefer to use the phrase *identity of relational frameworks*.

It is possible in general to understand isomorphism as a form of similarity. For suppose that A and B are isomorphic; then they share at least one property in common, namely their *relational framework*. Hence two isomorphic structures are similar, because their relational frameworks are identical. So two objects that exemplify isomorphic structures are ipso facto structurally similar. The similarity in case (2) between the bridge and its graph is precisely of this type. This is prima facie an interesting advantage that similarity enjoys over isomorphism. For neither similarity nor resemblance can *in general* be reduced to isomorphism.[12] Judgements of similarity unproblematically apply to any sort of objects, including for instance perceptual experiences, and it is unclear to say the least how these experiences could be said to exemplify structures at all. Whether or not such reduction is ultimately theoretically possible, in no ordinary context are we able to translate judgements of similarities in, say, taste, to isomorphisms between anything like "taste structures" of different types of food. Analogously for most judgements of resemblance. The basic problem is that similarity and resemblance are ordinarily and unproblematically applied to both response-dependent and intensionally defined properties, while isomorphism is not.

But what about those cases of representation where the source and target can be ascribed an explicit structural exemplification? Arguably, many scientific representations are of this sort. But even in these cases the reduction of similarity to isomorphism is typically only possible conditional on the appropriate exemplification of structure. Two objects may be similar in sharing just some of their properties, such as i.e. the colour distribution of their surfaces. So only the structures defined by the colour relation may be isomorphic. While it is correct to claim that such objects are similar, the isomorphism claim must be restricted to the specific properties shared.

Let us then suppose that either [iso] or [sim] were correct. It follows that to establish in cases 1-4 that the source is a genuine representation of the target, we need to investigate the properties of the source and those of the target, and the relationship between them. No further investigation is required. Similarity and isomorphism are the sort of extensionally defined relations that fall under the remit of scientific laws. Representation will then obtain if the right type of relational facts obtain between A and B, independently of any agent's judgements on the matter. Thus if we can show [iso] or [sim] to be correct we will *ipso facto* have *naturalised* the notion of scientific representation. This, I think, is to a large extent the motivation and driving force behind the [iso] and [sim] conceptions.[13]

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[12] Contrary to what is implied by French (2002), who bizarrely claims that "Van Fraassen … has argued that an appropriate account of resemblance can be given in terms of the set-theoretic relation of isomorphism (1994). This has been strongly criticised by Suárez (1999)". In fact Van Fraassen (1994) does not even attempt to give such an account, and Suárez (1999) does not refer to Van Fraassen's (1994) paper once! The passage is astonishing since Van Fraassen and I strongly agree that the notion of representation can not be reduced to any non-intentional notion, including isomorphism – see our symposium *The Pragmatics of Scientific Representation* at the recent PSA conference in Milwaukee. French's paper provides an extremely inaccurate and unreliable report on my views.

[13] The aim to naturalise scientific representation is clear in Giere's work, and may in fact be taken to be a constant in his intellectual trajectory. See for instance his (1988) and (1999). But Giere seems to understand the term "naturalise" differently, in the weaker sense of "may be studied by science" merely, and his use may turn out to be compatible with the theses defended here.

3. Means and Constituents of Representation.

I want to first distinguish the *means* and the *constituents* of representation. In practice the main purpose of representation is surrogative reasoning.[14] Suppose, for instance, that an object A represents an object B; then A must hold some particular relationship to B that allows us to infer some features of B by investigating A. Take for instance the example of the phase space representation of the motion of a classical particle. The graph may be similar in respects a,b,c to the particle's motion; and when we reason about the graph in order to infer features of the particle's motion we do so by studying precisely that similarity. The means of the representation are thus those relations between A and B that we actively make use of in the process of inquiring about B by reasoning about A. Notice crucially that an object A or system may hold more than one type of relation to another B, but at any one time only one of these will be the means of representation. For example, a phase space graph of the motion of a paper ball in air may be both structurally isomorphic to the ball's motion in space, and in addition similar to the ball in being drawn on the same type of paper. The similarity obtains but is not the means of the representation in this case (although there are circumstances in which it could be, for example if we were investigating the properties of paper, not motion!)

Thus there may be a great variety of means by which representation does its work: isomorphism and similarity are just two common ones, but there are others, such as exemplification, instantiation, convention, truth. In addition, the means of representation are not exactly transparent: no source wears its means of representation "on its sleeve". In many cases the actual means of a representation may be opaque to the uninitiated. Consider a bubble chamber photograph, an astronomical chart, or an equation of motion. To correctly understand what and how these sources ground inferences about their representational targets invariably requires informed and skilful judgement. Normally only one among the many relations obtaining between A and B is intended to provide grounds for such inferences. So much is common lore, particularly in the philosophy of art. It is surprising therefore that the implications of this simple observation regarding the nature of scientific representation seem not to have been picked out. In particular, I will argue, it follows that neither [iso] nor [sim], on their own, can account for the *means* of scientific representation.

At this point a distinction between the *means* of representation and its *constituents* may be drawn as follows. The fact that we use a particular relation (say, similarity) between A and B to, say, infer B's properties by reasoning about A's properties, should not be taken to mean that this relation is what *constitutes* the representation by A of B. There could be a deeper, hidden relation between A and B. Suppose that A (for instance, a phase space structure) represents B (the motion of a particle in space) in virtue of an isomorphism. This appears to be consistent with the fact that sometimes in reasoning successfully about B on the basis of A we need not employ or refer explicitly to the isomorphism of A and B, but are able to use some other relationship instead. For instance, on a particular occasion it may be possible to investigate the properties of a particle's motion merely by

[14] Swoyer, 1991.

investigating its similarity (i.e. shared properties, such as for instance the appearance of randomness) with its phase space graph. It would appear then that in this case the *means* of the representation (similarity) fail to agree with its deeper *constituents* (isomorphism).

We may thus attempt the following approximate definitions:

Means of Representation

At any time, the relation R between A and B is the *means* of the representation of B by A if and only if, at that time, R is actively considered in an inquiry into the properties of B by reasoning about A.

Constituents of Representation

The relation R between A and B is the constituent of the representation of B by A if and only if its obtaining is necessary and sufficient for this representation.

The distinction opens up a promising avenue for defending [iso] and [sim]. One could take [sim] ([iso]) as the basic *constitutive* notion at the heart of representation, which warrants the representational relation, while accepting that isomorphism (similarity) may be employed as useful *means* once [sim] ([iso]) has been established. For example, the isomorphism between a phase space structure and the motion of a particle could be said to be the efficient means for applying the relevant similarities of structure that warrant [sim], and hence representation. Or, alternatively, the observed similarity between two bridges may be taken to be merely an efficient means for us to take cognitive advantage of the deep structural isomorphism existing between the bridge's structures: the similarity is only a means to more efficient reasoning, but it is the isomorphism that actually warrants the representational relation, in accordance with [iso]. Hence [sim] ([iso]) may fully characterise the constituents of the relation of representation, while failing to characterise its means.

4. Five arguments against similarity and isomorphism

I will now present five arguments against [sim] and [iso].[15] The first argument is the simple empirical fact that neither [sim] nor [iso] can be applied to the full variety of uses of representational devices that crop up in the practice of science. Hence an analysis of the *means* of representation in terms of just one of these conditions would be unduly restrictive, and local, for a *substantial* theory of representation. However, as I pointed out above, the defenders of [iso] and [sim] have an easy retreat: they can argue that [iso] and [sim] are meant as substantial theories of the *constituents*, not the *means* of the representational relation; they are meant to describe the relation between A and B that must obtain for A to represent B, independently of what relations are actually employed by inquirers in drawing inferences about B on the basis of A. The retreat is perfectly

[15] The logical argument, the non-sufficiency argument and the non-necessity argument were first advanced in Suárez (1999). Frigg (2002) reiterates those arguments as well as providing some of his own.

honourable and legitimate, for it is line with the pretensions of a substantial naturalised theory of representation.

However, my other four arguments show that even in those cases where [iso] and [sim] apply, the analysis they yield is incorrect; in other words, the isomorphism and similarity conceptions can not on their own *constitute* representation. The second argument is that [iso] and [sim] lack some of the logical properties of representation. The third argument is that they do not allow for misrepresentation or inaccurate representation. The fourth argument is that [sim] and [iso] are not necessary for representation – they fail in some cases of successful representation. My fifth and final argument is that neither [iso] nor [sim] can be sufficient for representation, because they leave out the essentially intentional aspect of representation.

The Argument from Variety: [sim], [iso] do not apply to all representational devices.

Although similarity and isomorphism are among the most common means of representation in science neither one, on its own, covers even nearly the whole range. We have some firmed up intuitions, I think, about the means of representation in the four cases mentioned:

Case 1 (Toy bridge representation): Similarity is almost always the means for concrete physical representations of concrete physical objects. An engineer's toy bridge may be similar to the bridge that it represents in the proportions and weights of the different parts, the relative strengths of the materials and the geometric shape. It is by reasoning on the basis of these similarities that the source does its representational work. There are also important dissimilarities, such as size, which make the representation only a partially successful one, but similarity again seems to be a good guide to determining which parts are representational and which aren't. By contrast isomorphism, which is well-defined only as a relation between mathematical structures, does not apply directly to the relation between two physical objects described in (1). But it does apply to some abstract structures that are exemplified by these two objects, such as their geometric shape.

However, the representational use of the toy bridge is almost always grounded on actual reasoning about its properties, along with those of the real bridge, and not on the properties of the structures exemplified by either bridge. The means of the relation of representation are not in this case captured by the [iso] conception because this conception misidentifies its relata, which are the physical objects themselves, and not the structures exemplified. To make this point vivid, suppose for instance, that two concrete toy bridges exemplify exactly the same geometric structure, isomorphic to that of the larger bridge. We typically treat these two bridges as two different *means* and as distinct representations of the same object, but an isomorphism analysis of the *means* of representation does not allow us to do that: the relationship R that each toy bridge holds to the larger bridge is exactly the same. [16]

[16] In addition, questions of structure-exemplification are tricky. What structure is exemplified by a concrete object is a highly context and purpose dependent issue. Consider for instance, the many important

Case 2 (Graph of bridge): The range and depth of the dissimilarities between the source and the target become greater in this case: a piece of paper containing the graph of a bridge is only similar to the bridge it represents with respect to the geometric shape and proportions between the different points; nothing else is interestingly similar. This "similarity of structure" is better captured by the alternative conception [iso]. Maps, plans and graphs are typical cases where isomorphism is the means of scientific representation.

Case 3: (Billiard ball model): This case appears to be harder for both conceptions. A system of billiard ball is in not prima facie in any relevant sense similar to any state of nature. We may anyway refer to the relation of similarity or isomorphism that can obtain between two token instances of these things. If so we must make sure that we are referring to a similarity between the *dynamical* properties of the systems, collectively taken, as a system of billiard balls is similar to a system of gas molecules only in its dynamical properties, and in no properties of the entities taken individually at any one time – other than their elasticity. Mutatis mutandis for isomorphism: this obtains only between the mathematical structures exemplified by the dynamics of the systems, and not between the structures exemplified by the individual entities.

Case 4 (Quantum state diffusion equation): This case is simply not covered by the similarity analysis at all. A mathematical equation, written down on a piece of paper, represents a certain physical phenomenon but is not similar to it in any relevant respect. If the equation is dynamical, one may focus on the phase-space structure defined by the equation, and on that structure which is best exemplified by the phenomenon: if the equation is an accurate representation of the phenomenon, isomorphism will obtain between them and, as noted in section 1, isomorphism is a case of similarity.

But even [iso] is problematic here. In most cases of mathematical representation it seems farfetched to assume that the *means* of the representation is an isomorphism. It trivially is the case that the dynamic phase space structure exemplified by a differential equation must be isomorphic to the dynamic structure exemplified by the phenomenon, if the equation accurately represents the phenomenon. But when scientists reason about a differential equation in order to inquire into the phenomenon it represents, they rarely include an investigation of the formal properties of these structures. What they actively do is look for solutions to the equation given certain boundary conditions, and then check whether some parameters of those solutions correspond to observed features of the phenomena. The isomorphism which obtains is not what they explicitly reason about, so it is not in this case the *means* of the representation.

The Logical Argument: [sim], [iso] do not possess the logical properties of representation

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structures that a bridge may exemplify besides geometric shape: the structure of weights and forces, the distribution of colours of each of the parts, the relative resistances of each part to air and water friction, etc. This underdetermination of structure seems to me a major objection to any form of structuralism; but it is somehow tangential to my concerns here.

A substantive theory must make clear that scientific representation is indeed a type of representation; i.e. that it shares the essential phenomenological properties of ordinary representation. It is well-known that representation in general is an essentially non-symmetric phenomenon: a source is not represented by a target merely in virtue of the fact that the source represents the target. Merely because a painting portrays a person, it does not mean that the person stands for the painting. Merely because an equation represents a phenomenon, the phenomenon can not be said to stand for the equation. Representation is also non-transitive and non-reflexive. A theory of scientific representation must do justice to these phenomenological features.

Nelson Goodman[17] used these logical properties of representation to argue against resemblance theories, and his argument carries over against [sim] and [iso]. I shall pursue here an illuminating analogy with painting – a particularly apt analogy in this context, as [iso] and [sim] both assume that scientific representation is essentially an object-to-object relation rather than word-to-object relation[18]. Of course the argument is independent of the analogy, and is in no way exhausted by it. The purpose of the analogy is to call attention to the logical properties of the phenomenology of object-to-object representation, thus suggesting that scientific representation must display these properties too. It could however turn out that scientific representation is not a kind of object-to-object representation, or not entirely so; but this is a possibility that would *ipso facto* refute the [iso] and [sim] conceptions that I criticise here. To defeat the argument, one would have to show that [iso] and [sim] have the logical properties of representation in general, which I think is patently not possible.

Representation is non-reflexive: Diego Velázquez's portrait of Pope Innocent X represents the Pope as he was posing for Velázquez but it does not represent the portrait itself. It is not the case that object-to-object representation is *i*rreflexive, though: Velázquez astounded the world with the striking built-in reflexivity of *Las Meninas*, which represents among other things, the act of its being painted. A creative obsession with representing the very elusive act of representation is part of art since at least the Quantrocentto. But even in these cases the representation typically adds to the object, and also subtracts from it: the source and the target are not exactly identical.

It would be equally wrong to claim that the Pope represents the painting. We may put aside issues about whether a non-existing object can be said to represent: even when the Pope was sitting down posing for Velázquez it would not have been right to claim that he represented the painting. Representation is non-symmetric because it is always one-way.

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[17] Goodman, 1975, pp. 3-10.

[18] It is not surprising that [iso] and [sim] have been particularly attractive to defenders of the semantic view of theories. For on that view, theories are not linguistics entities but structures, hence objects. Eric Peterson (unpublished manuscript) argues that the only claim that is essential to the semantic view is that theories are not linguistic entities. Nothing that I have written contradicts that minimal claim. One might even agree with the view that theories are better conceived as structures, while not agreeing that representation is a structural relation. The inferential conception that I develop in part II is neutral on the issue of the nature of scientific theories, and may be adopted by defenders and opponents of the semantic view alike.

Apparent cases of symmetry, such as some of Escher's drawings, turn out on inspection to be cases where there is a distinct representational relationship going each way.

The recently deceased painter Francis Bacon was obsessed with Velázquez's portrait of Innocent X, and produced a large number of variations of his own, all of them intending to represent the Velázquez canvass. The Bacon variations allow us to infer much about both Bacon's and Velázquez's obsessions and skills as painters. But nothing can be reliably inferred from the Bacons about the Pope. The Bacon portraits represent not the Pope, but the Velázquez canvass. Representation is non-transitive, and in addition most apparent cases of transitivity invariably turn out to be cases in which the representational relationship between A and B is distinct from that between B and C.

However, similarity is reflexive and symmetric, and isomorphism is reflexive, symmetric and transitive. A glass of water is similar to itself, and similar to any other glass that is similar to it. Mutatis mutandis for isomorphism: A geometric structure (a square) is isomorphic to itself, and always isomorphic to any other structure (another square of perhaps a different size) that is isomorphic to it, and isomorphic to any structure that is isomorphic to a structure that is isomorphic to it (an even larger square).

The Argument from Misrepresentation: [sim], [iso] do not make room for the ubiquitous phenomena of mistargetting and/or inaccuracy.

Misrepresentation is an ubiquitous phenomenon in ordinary-life representation. It comes in two varieties. There is first the phenomenon of mistaking the target of a representation, or as I call it "*mistargetting*": often we mistakenly suppose the target of a representation to be something that it actually does not represent. Suppose that a friend of mine has disguised himself to look roughly similar to Pope Innocent X in the relevant respects. In seeing the Velázquez canvass for the first time I am struck by this resemblance and, ignoring the history and true target of the representation, I go on to suppose that the Velázquez represents my friend. This is a clear case of misrepresentation, but there is no failure of similarity to explain it. Indeed misrepresentation by accidental similarity would be impossible if [sim] were true, precisely because similarity would then warrant representation. Exactly the same argument goes mutatis mutandis for isomorphism, and it is an argument that can be easily transferred to cases of scientific mistargetting. Consider the case of the quantum state diffusion equation:

$$|d\psi\rangle = -i/h\ H\ |\psi\rangle\ dt + \Sigma_j\ (\langle L_j^*\rangle\ L_j - ½\ L_j^*\ L_j - ½\ \langle L_j^*\rangle\ \langle L_j\rangle)\ |\psi\rangle\ dt + \Sigma_j\ (L_j - \langle L_j\rangle)\ |\psi\rangle\ dt.$$

This equation represents the evolution of the quantum vector state of a particle subject to a diffusion process. (The first term is just the usual Hamiltonian in the linear Schrödinger equation, the other two terms account for random diffusion and interaction with a larger environment.) A mathematician who knew nothing about quantum mechanics would be able to solve this equation for some boundary conditions; by accident the motion described may correspond to a particular classical particle's Brownian motion. This

accidental fact on its own does not turn the equation into a representation of the particle's motion, however, because the essential intentionality of representation is missing.

The point has been argued persuasively in the general case by Putnam and in the scientific case by Van Fraassen [19], and need not be rehearsed in detail here. It has long been noted within the philosophy of art too. Thus Richard Wollheim writes (1987, p. 54): "The connection between seeing-in and representation was noted by theorists of representation both in antiquity and in the Renaissance. Yet almost to a person these thinkers got the connection the wrong way round: they treated seeing-in as – logically and historically – posterior to representation. For they held that, whenever we see, say, a horse in a cloud, or in a stained wall, or in a shadow, this is because there is a representation of a horse already there – a representation made, of course, by no human hand. These representations, which would the work of the gods or the result of chance, wait for persons of exceptional sensitivity to discern them, and then they deliver themselves up." For Wollheim, like Putnam, Van Fraassen and myself, the skill and activity required to bring about the experience of seeing-in (the appreciation by an agent of the 'representational' quality of a source), is not a consequence of the relation of representation but a condition for it.

Similarly for scientific representation. For suppose Putnam, Van Fraassen and Wolheim were all wrong on this point: [20] A mathematician's discovery of a certain new mathematical structure (defined by a new equation perhaps) unknown to be isomorphic to a particular phenomenon would amount to the discovery of a representation of the phenomenon – independently of whether the mathematical structure is ever actually applied by anyone to the phenomenon. The history textbooks would have to be rewritten so that it was Riemann, not Einstein, who should get credit for first providing a mathematical representation of spacetime.

The second form of misrepresentation is the even more ubiquitous, perhaps universal, phenomenon of inaccuracy. Most representations are to some degree inaccurate in some or other respects. [iso] can not account for inaccurate representation at all. For on this conception either a model is a representation of, and thus isomorphic to, its target, or it is not a representation at all. [sim] requires that the target and the source must share some although not necessarily all their properties. Hence [sim] can account for the type of inaccuracy that arises in an incomplete or idealised representation of a phenomenon, i.e. one that leave out particularly salient features such as the highly idealised representation of classical motion on a frictionless plane. But this won't always help to understand inaccurate representation in science, where the inaccuracy is much more often quantitative than qualitative. For example Newtonian mechanics, without general relativistic corrections, can at best provide an approximately correct representation of the solar system. Some motions would not be quite as predicted by the theory, even if all features of the solar system were to be accounted for. The interesting question is not what properties fail to obtain, but rather how far is the divergence between the predictions and

[19] Putnam, 1981, chapter 1. Van Fraassen, 1994, p. 170.
[20] The historical example was brought to my attention by Roman Frigg.

the observations regarding the values of the properties that do obtain. [sim] offers no guide on this issue.

The Non-Necessity Argument: [sim], [iso] are not necessary for representation – the relation of representation may obtain even if [sim], [iso] fail.

It is trivial that any object is in principle similar to any other object. In fact the point is often made that if all logically possible properties are permitted, then any object is similar to any other object in an infinite number of ways, i.e. there is an infinite number of properties that we can concoct that will be shared between the objects ("being on this side of the moon", "being neither black nor blue", etc). If so, similarity would be necessary for representation but in a completely trivial way. For it would not only be a necessary condition on representation but also on non-representation.

The defender of similarity may retort that it is not fair to include those logically possible shared properties that have nothing whatever to do with the representation itself (such as "being on this side of the moon"). A restriction is needed here to only those properties or aspects of the source and the target that are "relevant" to the representational relation: A represents B if and only if A and B are similar *in the relevant respects*. It is not the case that any source is in principle trivially similar in the relevant aspects to what it represents. Suppose that I am interested in representing in a painting the colour of the ocean in front of me. I may represent the ocean by painting some blue and green stripes on a piece of paper. Representation obtains in this case if the colours on my paper are similar to those of the ocean, and it fails otherwise: that is the only relevant property. Any other logically possible similarity, such as "being on this side of the moon", is irrelevant to this particular representation.

There are two important objections to this move. First, what is the criterion of relevance invoked here? This criterion must presumably link relevance to the representational relation itself, for otherwise there would be no reason to expect *relevant similarity* to be necessary for representation. The shared properties that are relevant are precisely those that pertain to the representation. So, we obtain that, A represents B if and only if A and B are similar in those respects in which A represents B. However illuminating this may be about the actual use of similarity, it is circular as an analysis of representation!

But then, and this is the second objection, it isn't that straightforward that similarity with respect to *relevant* properties is in practice necessary for representation. This is made most vivid in the analogy with art, and to illustrate this point I like to invoke *Guernica*, the well-known painting by Picasso. There are similarities between parts of this painting and many objects, such as a bull, a crying mother upholding a baby, an enormous eye. The all seem undeniably relevant to the representational content of the painting, if any similarities are, yet none of these similarities is a good guide to the actual targets of the representation. There are at least two targets. Picasso was interested in representing the first ever carpet-bombing of an entire civilian population: the bombing, under Franco's

consent if not direct orders[21], of the Basque town of Guernica by Hitler's Condor Legion and Mussolini's Aviazione Nazionale in 1937. In addition *Guernica* represents the threat of rising Fascism in Europe, which is the reason why it was hugely effective in bringing world attention to the Spanish Republic's cause. This is all historically well documented.[22] The point is that none of the targets of *Guernica* can be easily placed in the relevant similarity relation with the painting, and mutatis mutandis for isomorphism.[23]

The case in science is not significantly different. An equation – i.e. the actual physical signs on the paper— is as dissimilar as it could be from the phenomenon that it represents. Mutatis mutandis for isomorphism, as we have already seen in the case of inaccurate representation. We are perfectly happy with the claim that Newtonian mechanics provides a representation of the solar system, even if it is clear that Newtonian mechanics, without general relativistic corrections, is empirically inadequate and non-isomorphic to the phenomena of planetary motion. [24]

The Non-Sufficiency Argument: [Sim], [Iso] are not sufficient for representation –the relation of representation may fail to obtain even if [sim], [iso] hold.

The previous four arguments already point to a feature of representation that is not captured by the [iso] or [sim] analyses: the essential intentionality of representation. This was perhaps most apparent in the discussion of the *argument from misrepresentation*. The object that constitutes the source of a model has no directionality per se, but in a genuine representational relation the source *leads* to the target. Neither similarity nor isomorphism can capture this capacity of the representational relation to take an informed and competent inquirer from consideration of the source to the target. But it is this feature that lies at the heart of the phenomenological asymmetry of representation. Consider for instance two identical glasses. They share all their (monadic) properties, and are hence as similar as they could be. But neither of them leads to the other unless they are in a representational relation, and then only that which is the source will have the capacity to lead to the target. Or consider the trajectory in phase space described by the state vector

[21] Preston (1993, chapter IX).
[22] Blunt (1969),written in the midst of the cold war, probably over-emphasises the political aspects of *Guernica*. Chipp (1989), written during the controversy over *Guernica*'s return to the new Spanish democracy, and involved in the international diplomatic efforts that ensued, definitely under-emphasises them. The most balanced account may remain Arnheim's (1962).
[23] I employ *Guernica* to the same effect in Suárez (1999). French (2002) misreports my argument as one of ambiguity between different targets, and then, confusingly, goes on to write in response that "it is not difficult to find other examples from the history of art which might be called non-representational" (p. 5). Ambiguity is no problem for [iso], since it is always possible for different objects to exemplify isomorphic structures. Nor am I claiming that *Guernica* is non-representational: that would be an absurd claim, and moreover one that would bypass what's at issue, namely whether there can be representation without isomorphism. My claim is that it makes no sense, and it would be false, to assert that either of these two genuine targets of *Guernica* is isomorphic, or similar in the relevant respects, to the canvass.
[24] A possible retort on behalf of [iso] and [sim] is that we should concentrate entirely upon the subset of properties, or the substructure, that corresponds to those motions that are correctly predicted. But in cases of quantitative inaccuracy this normally won't help. Newtonian mechanics arguably does not describe *any* actual planetary motion in a quantitatively fully accurate way.

of a quantum particle. Unbeknownst to us this trajectory may well be isomorphic to the motion in physical space of a real classical particle. But unless the phase space model is intended for the particle's motion, the representational relation will fail to obtain. Hence neither similarity nor isomorphism are sufficient for representation.

There is an additional reason why isomorphism is not sufficient for scientific representation. It is related to the notion of structure-exemplification. Goodman has provided a useful analysis of the notion of exemplification as a special class of representation.[25] For Goodman, if x exemplifies y, then x denotes y, and viceversa; but x may denote y without exemplifying it: exemplification requires denotation both ways. My sweater exemplifies red if and only if it both denotes red and is denoted by red (i.e. the sweater is used to refer to red and also *is* red.)

Now let us suppose that this analysis of exemplification goes through for structural representation. Then whenever object x exemplifies structure y it both represents y and is represented by y. It follows then that for an object A to represent some object B by means of [iso], the structure exemplified by A must be isomorphic to the structure exemplified by B. But that just means, if the supposition is right, that for A to represent B there must be a structure that represents A isomorphic to a structure that represents B. And we will now want to ask how the structures represent the objects in the first place.

Now, recall the discussion of the quantum state diffusion equation in the *argument from variety*. We established then that isomorphism is not the means of the representation in this case. Could it be the *constituent* of the representational relation? Perhaps mathematical representation by means of differential equations is precisely the type of representation for which the means / constituents distinction is appropriate. But [iso] stipulates that in order to represent a phenomenon by means of an equation we need to independently describe the structure exemplified by the phenomenon. For remember that isomorphism is defined as a relation between mathematical structures. However, as we have seen, for the purpose of establishing a theory of the constituents of representation, this will be circular:[26] A will represent B if and only if the structure that represents A is isomorphic to the structure that represents B.

For instance, the quantum state diffusion equation for a localising particle describes a random walk motion in a phase-space structure. This structure represents not the particle's motion, but a representation of it, namely the motion of the vector in Hilbert space that corresponds to the state of the particle. But representing a representation of *x* is in no way equivalent to representing *x*; and we are left with the question of how *x* is mathematically represented in the first place. So isomorphism is not in general sufficient for representation. Perhaps paradoxically the case of representation of a well established physical phenomenon by means of a differential mathematical equation is the hardest case for [iso] to accommodate.

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[25] Goodman (1975, pp. 52 ff).

[26] Although [iso] may help for other purposes, such as explaining the *accuracy* of structural representations.

5. The Amended Versions Fare no Better

A recurrent theme in these arguments, which is most apparent in the discussion of the *non-sufficiency argument*, is the appeal to the essential intentionality of representation: a necessary condition for A to represent B is that consideration of A leads an informed and competent inquirer to consider B. I will refer to A's capacity to lead a competent and informed inquirer to consider B as the <u>representational force</u> of A. Representational forces are determined at least in part by the intended use of informed agents: A can have no representational force unless it stands in a representing relation to B; and it can not stand in such a relation unless it is intended as a representation of B by some suitably competent and informed inquirer.

Can [iso] and [sim] be made to work by simply amending them to account for this intentional component? The amended versions would look as follows:

[sim]': A represents B if and only if i) A is similar to B and ii) the representational force of A points to B.

[iso]': A represents B if and only if i) the structure exemplified by A is isomorphic to the structure exemplified by B and ii) the representational force of A points to B.

The first thing to notice about these amended versions is that they abandon the aim of naturalising representation. Representation can no longer be established by means of a scientific investigation of the facts of the matter – for there are elements in the relation of representation, namely the *representational forces* in part ii), that essentially involve value judgements, and are not reducible to the facts that fall under the remit of natural laws. [27]

But in fact, [sim]' and [iso]' can not be correct. Certainly the additional clause stipulating the intended use of the representation turns conditions [iso]' and [sim]' into sufficient conditions for representation, and the *non-sufficiency argument* no longer applies. But the other arguments still apply. The *non-necessity argument* is, if anything, strengthened as the necessary conditions on representation are now stronger. The *argument from variety* shows that neither [iso]' nor [sim]' can describe all the *means* of representation; while the logical, misrepresentation and non-necessity arguments show that they do not provide a substantial theory of the *constituents* of representation. Simply adding further conditions to [iso] or [sim] to make room for the essential intentionality of representation will not help.

[27] Representational forces are determined at least in part by intended uses, which in turn are typically conditioned and maintained by socially enforced conventions and practices: thus they may be considered to some extent objects of study of some of the social sciences. The discipline where the study of representational forces comes to the fore is surely history: a good deal of historical research is in one way or another devoted to objectively settling issues of past representational forces. Historians have developed some sophisticated tools to carry out these tasks. Baxandall (1985), for instance, was an influential milestone in the history of art. But although science can study values, it can not reduce them to facts and their laws.

6. Weakening similarity and isomorphism.

The prospects for a substantial naturalistic theory of representation seem bleak. Certainly [sim] and [iso] are non-starters. In this final section I take a look at a number of attempts to weaken the conditions on representation imposed by [iso] and [sim]. These programmes are either being tentatively developed at present or could be developed. So my conclusions have a correspondingly tentative and provisional character.

Similarity without Identity

The problem then lies not with what [iso] and [sim] lack but with what they've got. We must try to subtract from, not add to, these conditions. One assumption that was built into [sim] is the identity-based theory of similarity. This theory seems natural, gives a high level of precision to the concept, and makes it possible for us to quantify and measure degrees of similarity between objects (as ratios of properties shared). But it may be mistaken.

Eileen Way [28] has found evidence within experimental work in cognitive psychology for a non-identity based understanding of similarity, which emphasises the essential role of contextual factors and agent-driven purposes in similarity judgements. (In the terminology of this paper, this turns [sim] into a non-naturalistic theory.) Let us suppose that similarity between two objects is not simply a case of sharing a property, but a more complex contextual relation. We don't have a very good understanding of what this relation may be, but Eileen Way argues that on such theories of similarity there is typically no reason to expect similarity judgements to be symmetric: The fact that A is similar to B does not *ipso facto* require B to be similar to A. If Way is right the *logical argument* does not cut as strongly against similarity as it seemed. But it applies nonetheless. For however similarity is conceived, it must be reflexive. If something is not similar to itself then it is not similar to anything else. Any theory of similarity must concede this: similarity comprises identity; identity is a limiting case of similarity. Here representation and similarity definitely depart, for the vast majority of representations patently do not represent themselves.

However the combination of Giere's emphasis on the essentially intentional element in similarity judgements[29] with Way's non-identity based understanding of similarity would undeniably bring similarity and representation closer. Such a theory would be successful to the extent that it builds the representational force of the source into the relation of representation itself: it would be a non-naturalistic theory in the terminology of this paper. The *non-sufficiency argument* would have no force against such a theory, and neither would the mistargetting part of the *argument from misrepresentation*, or the non-symmetry part of the *logical argument*. Reflexivity and the *non-necessity argument*

[28] In her talk at the Las Cruces modelling conference, Las Cruces, New Mexico, January 2002.
[29] Giere (forthcoming).

would remain the standing blocks for this interesting non-naturalistic theory of representation as similarity.

Homomorphism

The [iso] condition sometimes gets weakened in a variety of ways, which solve some but not all of the problems that I have raised. Following the pioneering work of Krantz, Suppes et al (1971), Brent Mundy employs the notion of homomorphism, and shows how to apply it to measurement theory, spacetime geometry and classical kinematics. We say that an extensional structure A is faithfully homomorphic to an extensional structure B if and only if there is a function that maps all the elements in the domain of A into the elements in B's domain, while preserving the relations defined in A's structure. More precisely, suppose that A and B uniquely exemplify the structures $< D, P^n_j>$ and $< E, T^n_j >$; where D, E are the domains of objects in each structure and P^n_j and T^n_j are the n-place relations defined in the structure. Then A is *faithfully homomorphic* [30] to B iff there is a mapping $f: D \rightarrow E$, such that for any n-tuple $(x_1,\ldots, x_n) \in D$: $P^n_j [x_1,\ldots, x_n]$ if and only if $T^n_j [f(x_1),\ldots, f(x_n)]$. The correspondingly weakened version of [iso] is:

The *homomorphism conception of representation* [homo]: A represents B if and only if the structure exemplified by B is homomorphic to the structure exemplified by A.

A homomorphism is, unlike an isomorphism, neither one-to-one nor onto, so the cardinality of A and B may differ. This feature was notoriously used by Krantz, Suppes et al (1971) to show that [homo] rather than [iso] is appropriate for theories of measurement. The important advantage that [hom] enjoys over [iso] is then the ability to deal with partially accurate models. Parts of a source may not represent any of the aspects of the homomorphic target. So the hope is that [hom] will be able to refute the part of the *argument from misrepresentation* that refers to inaccurate representation, and its consequences for the *non-necessity argument*. The solar system may only be represented by the part of the Newtonian model that asserts the number of planets and their average proximity to the sun, without specifying their precise motions. The highly developed structural theory of measurement as homomorphism into the real number continuum allows [homo] to provide precise estimates for these numbers. [31] It seems clear that the move to [homo] weakens the *non-necessity argument* (although interestingly it does not dispel the force of the art analogy in that argument).

However, all the other arguments apply against [homo] too. This includes the *argument from variety*; the mistargetting part of the *argument from misrepresentation*; and the *non-sufficiency argument*. The *logical argument* is significantly weakened but not avoided: Homomorphism is neither symmetric nor transitive, but it is reflexive.

Partial Isomorphism

[30] Mundy (1986, p. 395).
[31] Krantz, Luce, Suppes and Tversky, (1971). A good historical summary is Díez (1997).

Another proposal to weaken [iso] may be provided by Mikenberg, Da Costa and Chuaqui's (1986) notion of partial structure, and the corresponding notion of partial isomorphism introduced by Bueno (1997). A partial structure $\langle D, R_{i1}, R_{i2}, R_{i3}\rangle$ defines for each relation R_i a set of n-tuples that satisfy R_i, a set of n-tuples that do not satisfy R_i, and a set of n-tuples for which it is not defined whether they satisfy R_i or not. Given two partial structures $A = \langle D, R_{i1}, R_{i2}, R_{i3}\rangle$ and $B = \langle E, R'_{i1}, R'_{i2}, R'_{i3}\rangle$ "the function $f: D \rightarrow E$ is a partial isomorphism if i) f is bijective, and ii) for every x and y $\in$ D, $R_{i1}(x,y)$ if and only if R'_{i1} (f(x), f(y)) and R_{i2} (x,y) if and only if R'_{i2} (f(x),f(y))" (Bueno, 1997, p. 596; French and Ladyman, 1999, p. 108). The corresponding theory of representation would then be:

The *partial isomorphism conception of representation* [partial iso]: A represents B if and only if the structure exemplified by A is partially isomorphic to the structure exemplified by B.

The advocates of partial isomorphism argue that the introduction of R_{i3} serves to accommodate the partiality and openness of the activity of model building. That may be so, but as a theory of representation [partial iso] fares even worse than [homo]. Since according to i) *f* is bijective, it follows from ii) that $R_{i3}(x,y)$ if and only if $R'_{i3}(f(x),f(y))$, and hence partial isomorphism reduces to three separate isomorphisms. So it remains to be seen whether [partial iso] can avoid the inaccuracy part of the argument from misrepresentation, and correspondingly weaken the non-necessity argument. Even if this could be done, [partial iso] would be at a disadvantage with respect to [homo] since the logical argument weighs even more strongly against [partial iso]: partial isomorphism, unlike homomorphism, is symmetric.

Structural Representation without Isomorphism

Other writers within the structuralist tradition have been more cautious. It does not follow from the claim that theories (or models) are, or contain, structures that the relation that constitutes representation is a structural one. The arguments that I have presented in this paper suggest that we should look elsewhere for the constituents of representation, perhaps even in those cases where the source and the target of the representation *are* structures.

Chris Swoyer[32] for instance rightly claims that "structural representation is not a necessary condition for representation in the ordinary sense of the word, since with sufficient perserverance – or perversity – we can use anything to represent virtually anything else, and in many cases the two things won't have any interesting structural similarities at all. And it is not sufficient for ordinary representation, since if you can find one structural representation of something, you can usually find many." Swoyer is also precisely right in characterising structural representation as having the "potential" to be used in surrogative reasoning about its target.

[32] Swoyer (1989), p. 452. See also Díez, 1998.

After having considered six different phenomenological constraints upon structural representation, Swoyer proposes the notion of an Δ/Ψ-morphism.[33] Consider the representation of some structure B by means of another structure A; and consider two subsets of B's domain Δ and Ψ. Then Swoyer's notion is as follows: [34] A structure A *structurally represents* another structure B iff there is a (neither necessarily one-to-one nor onto) mapping *c: B → A* that preserves all the relations defined over Δ and counter-preserves all the relations defined over ψ, where ψ is non-empty. Since ψ is non-empty, structural representation serves always to carry out surrogate reasoning about its target. Swoyer's notion does not meet the logical, misrepresentation and non-sufficiency arguments presented here (in particular Δ/Ψ-morphisms are reflexive); neither is it meant to do so, since it is not meant as a theory of scientific representation in general. Yet it goes to show that [iso], [hom] and [part iso] do not correctly describe even the means of *structural* representation!

[33] Swoyer's constraints implicitly rule out isomorphism, homomorphism and partial isomorphism as the relation of structural representation. In this regard his work adds weight to my critique of [iso] and its cousins.

[34] This is in fact Swoyer's "penultimate" definition. His final proposal includes an additional refinement to account for the further distinction between cases in which the representation correlates elements of B uniquely to elements of A and those in which the representation correlates elements of A uniquely to elements of B. Since the distinction is only required to cover cases of linguistic representation, I ignore it here.

PART II: AN INFERENTIAL CONCEPTION OF SCIENTIFIC REPRESENTATION

7. Elements of a Theory of Scientific Representation

The first demand on a satisfactory theory of representation is then that it must defeat the five arguments in part I; and this minimally requires making explicit what I call the *representational force* of a source, or its *force* for short. This is the capacity of a source to lead a competent and informed user to a consideration of the target. *Force* is a relational and contextual property of the source, which is fixed and maintained in part by the intended representational uses of the source on the part of agents. No object or system may be said to possess representational force in the absence of any such uses. The contextual character of the ascription of force to sources is made vivid by examples of sources that represent various different targets. A spiral staircase, for example, may be taken to represent the mechanics of a spring, or the structure of DNA. Here the source's force varies with intended use. A consideration of the source will lead an informed and competent user of each of these representations towards the correct target; if an agent is simultaneously competent and informed about the use of both representations, or ambivalent, the force of the source will be double or ambiguous respectively.

The second demand on a satisfactory theory is that it must explain why common means of representation, such as similarity and isomorphism among others, are successful. It must tell us what it is about these relations that allows us to use them to represent objects and systems in nature.

A third demand is related to the distinction between the means and the constituents of representation. This is a distinction that I introduced in order to savage the [iso] and [sim] conceptions from the *argument from variety*. The distinction is theoretically clear – but is it ever borne out in practice? In the actual practice of representation, in science and elsewhere, is it possible to distinguish the means-relation between source and target from the constituent-relation? It turns out that the distinction is most elusive in practice, and this suggesting that it is a theoretical artefact.

Recall how I introduced the means-constituents distinction. A phase space graph of the motion of a paper ball in air may be both structurally isomorphic to the ball's motion in space, and in addition similar to the ball in being drawn on the same type of paper. It is then possible to assert that this isomorphism constitutes the relation whereby A represents B, and this appears to be consistent with the fact that sometimes in reasoning successfully about B on the basis of A we need not employ or refer explicitly to this isomorphism, but to some other relationship between A and B. This may be for instance the similarity mentioned above in type of paper. Or more plausibly, some other similarity between the particle's motion and the graph, such as an obvious appearance of an upwards trend in both, or randomness. It seems then that the *means* of the representation (similarity) fail to agree with its deeper *constituents* (isomorphism).

A little reflection shows however, that what we have introduced by means of this example is not an instance of the theoretical distinction between means and constituents, but rather two distinct means of representation. Each is defined in terms of the different patterns of reasoning and inference that an enquirer may use on the same source and target. Thus these are not two different descriptions of the same representation, but rather two different representations. When we move from one to the other we are not moving up one level on the abstraction scale, but are rather moving across in order to change the representation itself. One representation shows that a particle's motion is isomorphic to a graph, the other shows it to share some properties with the graph. My conjecture is that any apparent concrete instance of a means / constituents dichotomy will actually turn out to be, on closer inspection, a case of two different representational means applying to the same source-target pair.

To sum up, there are three important constraints on a satisfactory theory of representation. Firstly, the theory must avoid the objections raised by the logical, misrepresentation, non-sufficiency and non-necessity arguments. This can only be achieved if *force* is made an explicit condition on representation. Secondly, it must explain why isomorphism and similarity, among others, are appropriate means of representation within each of their domains. Thirdly, it must explain why the means / constituents distinction is elusive in practice. Note that the demands are not as strong as may appear. I already emphasised for instance that a satisfactory theory need not distinguish good from bad, true from false or accurate from inaccurate representations.

8. Representation and Surrogative Reasoning: Three Proposals

A couple of recent proposals go a considerable way towards meeting these demands. Ibarra and Mormann (2000) reject isomorphism as a basis for scientific representation while suggesting that the notion of *homology* may provide a more appropriate basis for a sound theory. The use of homology in this context is suggested by Hertz's discussion of modelling in *Prinzipien der Mechanik*. A model of a system, according to Hertz, provides us with a representation such that the "intellectually necessary consequences" of the model represent the "naturally necessary consequences" of the system. The advantages of characterising Hertz's insight in terms of homology as opposed to an isomorphism are several: the target and source need not be the same type of entity, and specifically they need not be structures; and the relation between them need not be structural; hence the dynamical functions that give rise to the "intellectually necessary conditions" of the model need not in any way resemble the dynamical functions that give rise to the "naturally necessary conditions" of the model. Only the end point of these processes stand in a representational relation.

RIG Hughes (1996) *DDI model* (denotation-demonstration-interpretation) develops Nelson Goodman's (1975) account into a fully fledged theory of scientific representation. Hughes also makes use of Hertz's insight. According to Hughes, scientific representation may be usefully analysed as a three part notion, which includes the *denotation* of physical

systems and their properties at any one time by means of elements of a model including equations, diagrams, etc; the *demonstration* of the dynamical consequences of the model; and the *interpretation* of these consequences back in terms of the physical system and its properties at a later time.

Both approaches have several important virtues.[35] Unlike [sim] and [iso], they take surrogative reasoning to be the primary function of scientific representation; and they point out the essential role of representational *force*. However, instead of taking these two features as the defining features of representation, these proposals seek some deeper constituent relation between the source and the target that will exhibit these features as a by-product. In doing this, they fail to meet all the demands that I have placed on a satisfactory theory of representation. Ibarra and Mormann's homology fails to meet the logical, misrepresentation and non-sufficiency arguments, since homology obtains whenever an agent's reasoning about A would enable inferences about B, regardless of whether A's representational force in fact points to B. Hughes' *DDI model* is not a general theory of representation, since denotation, demonstration and interpretation are neither separately necessary nor jointly sufficient conditions on scientific representation. But if we put the issue of generality aside, Hughes' DDI models is closest to the inferential conception that I develop in this paper. The requirement of denotation takes care of *force*; while the requirement of demonstration distinguishes minimally representation from mere stipulation.

There are however two deep and important differences. First, for Hughes representation involves demonstration essentially, and hence requires the actual carrying out of inferences about the target on the part of some agent. In this particular regard the notion of homology seems to have an advantage, and the inferential conception that I will defend does not require the actual carrying out of any of the relevant inferences. Second, Hughes' (and Goodman's) denotational criteria would rule out fictional representation, i.e. representations of non-existing entities. Goodman[36] notoriously tried to get around this problem by appealing to the exemplification of conventionally accepted features of fictional entities. For instance, a picture of a unicorn is a "representation" in the sense that the picture exemplifies some features (a horse, and a horn) that are conventionally ascribed to the corresponding fiction. We may then properly speak of the picture of a unicorn as a "unicorn-picture". Thus what "unicorn-pictures" have in common is not that they denote the same entity or class of entities, but rather that they exemplify the same features. However cunning this solution is, it can not obscure the fact that on any theory of representation as denotation, there is always a sharp difference between a representation of a real object – where the source denotes the target – and a "representation" of a fictional object – which does involve the denotation of what is purportedly represented, and which can only be said to be a "representation" in some derived sense. On the inferential conception to be presented in this paper, on the other hand, there is absolutely no difference in kind between fictional and real-object representation – other than the existence or otherwise of the target.

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[35] In some ways the inferential conception that I defend in this paper is an extension of these approaches – I am grateful to Andoni Ibarra and RIG Hughes for sending me their work.
[36] Goodman (1975), pp. 21ff. See also Elgin (1997), chapters 8, 9.

9. An Inferential Conception of Scientific Representation.

I propose that we adopt from the start a deflationary attitude and strategy towards scientific representation, in analogy to deflationary or minimalist conceptions of truth, [37] or contextualist analyses of knowledge. [38] Adopting a deflationary attitude has two important consequences. First, it entails abandoning the aim of a substantial theory to seek necessary and sufficient conditions on representation. 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 surrogative reasoning is another.

We may express the first feature as follows:

Condition 1: A represents B only if the representational force of A points to B.

While this condition on its own accommodates some kinds of ordinary representation, such as (on most accounts) the relation of signs to things signified, it can not accommodate scientific representation. For this feature would be satisfied by a mere stipulation of a target for any source. On theories that take representation to be denotation, such as Goodman's, this is indeed as it should be. I can for instance stipulate that "Samuel" will name my son, thus establishing a representational relation in virtue of a mere act of denotation.

But this is not how representation works in science. Scientific representation adds a characteristic form of objectivity to the phenomenological features of ordinary representation. The graph of the Forth Rail Bridge may be taken to represent the City of Edinburgh in a literary or metaphorical sense, as an emblem; but there is no interesting sense in which this representation can be said to be a part of science – not at any rate to the extent that it is a completely conventional sign for it, for in that case it can convey no *specific information* regarding the city, i.e. no information that any other sign could not equally convey. Similarly the quantum state diffusion equation can be taken to represent someone's mental or cognitive state in a metaphorical sense. Although these are representations they are not "objective". I do not mean by this that they are not true nor accurate – most scientific representations are neither. Nor does the argument depend on the targets being non-scientific objects. For neither the graph nor the equation might be taken to represent nuclear fission, for instance, in anything other than a metaphorical sense. By "objective" in this context, I mean *informative*.

[37] Horwich (1990); Field (1986).
[38] Williams (1996).

More generally the extension of denotational theories of representation to iconic and scientific representation has at least one problematic and counter-intuitive consequence. Suppose that I stipulate that the paper on which I am writing represents the sea, and the two pens that I use to write represent ships on the sea. This act of denotation allows us to correctly draw a few inferences about the ship-on-sea system on the basis of a consideration of the pens-on-paper system, such as for instance that the trajectories of ships may cross and that they may crash. I may have just as well stipulated that the pens will represent the sea and the paper will represent the ships; but this correlation seems counter-intuitive and unnatural. It is certainly less informative, since the relative movements of pens and paper can not allow us, for instance, to infer the possibility that the two ships may crash. The ships-on-sea system is more "objectively" characterised by the first denotational arrangement than by the second.

The *objectivity* of scientific representation is the source of the pervasive metaphor that links it to mirroring. For mirroring seems *prima facie* to characterise it appropriately: the graph "mirrors" the bridge but neither "mirrors" Edinburgh; the equation "mirrors" the motion of a state of a particle and not a mental state; neither of these "mirrors" fusion; and the ship-on-the-sea is "mirrored" by the pen-on-the-paper system, rather than the paper-under-the-pen system. Dyadic relations such as correspondence truth, isomorphism or similarity are then brought to the fore as concrete specifications of the mirroring metaphor. Do these relations capture the objectivity of scientific representation? They would, I think, if it was possible to turn them into theories of representation in the first place. But alas it is not possible to do so: None of the proposed specifications of mirroring (truth, similarity, isomorphism) meet the objections raised by the *variety*, *logical*, *misrepresentation*, *non-sufficiency* and *non-necessity* arguments. There is a tension between the *objectivity* of scientific representation, and the phenomenological features of representation in general.

I have already provided detailed arguments against isomorphism and similarity. To briefly illustrate the failure of mirroring conceptions let us here consider truth. Suppose then that we try to characterise the objectivity of scientific representation by means of truth as follows:

Condition 2: A represents B only if (i) the representational force of A points to B, and (ii) A is true of B.

This will be too strong regardless of how we interpret "true". Condition 2 applies only to linguistic representations, while we would like the analysis to be as general as possible; and it makes no room for representation of phenomena that fails to be completely accurate or truthful. From the point of view of the Kepler-Newton model, for example, the Ptolemaic model is an incorrect representation of the solar system; but it is *a* representation of the solar system nevertheless.[39]

[39] The fact that truth can not capture the *objectivity* of scientific representation in no way suggests that empirical adequacy will do. For condition 3: *A represents B only if (i) the representational force of A points towards B, and (ii) A is empirically adequate of B*, is inadequate for precisely the same reasons.

The mirroring metaphor is not a particularly helpful one. But if truth, isomorphism and similarity can not be used to capture the objectivity that distinguishes scientific representation, what can? I suggest that we explicitly turn to the second surface feature of scientific representation, i.e. its capacity to allow surrogative reasoning. We may formulate the inferential conception of representation as follows:

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

This condition states two minimal requirements for representation in science. They are stated as requirements on the putative source of a representation, given a putative target. But the reference to the presence of agents and the purposes of inquiry is essential. First, the establishing and maintaining of representational force in (i) requires some agent's intended uses to be in place; and these will be driven by pragmatic considerations. Second, the type and level of competence and information required in (ii) for an agent to draw inferences regarding B on the basis of reasoning about A is a pragmatic skill that depends on the aim and context of the particular inquiry.

[inf] is an abstract description that holds when and only when some concrete representational means apply. It is a scheme that will be filled in differently in each instance of representation. For instance, [inf]'s part (i) leaves open the issue of how many agents are required in a scientific community to fix the representational force of a source, and what the structure of the community and its practices ought to be in order to determine this force. Part (ii) leaves open the issue of what A's internal structure ought to be like in order to yield correct inferences about B. In particular it does not require that A allow deductive reasoning and inference; any type of reasoning – inductive, analogical, abductive — is in principle allowed, and A may be anything as long as it is the vehicle of the reasoning that leads an agent to draw inferences regarding B.

In scientific practice, the requirements expressed in part i) and part ii) stand in a dynamical equilibrium. On the one hand the specification of the source and its representational force in part i) constrains the level of competence and information required of an agent for representation; on the other hand an inquiry into the inferential capacities of A may lead either to shifts in the force of A, or to a reconsideration of what an appropriate source is to represent a given target B. As an example consider the derivation of the quantum state difussion equation for a measurement process from the stochastic differential equation for the state vector:

$$|d\psi\rangle = -i/h\, H\, |\psi\rangle\, dt + \Sigma_j \left(\langle L_j^* \rangle L_j - \tfrac{1}{2} L_j^* L_j - \tfrac{1}{2} \langle L_j^* \rangle \langle L_j \rangle\right) |\psi\rangle\, dt + \Sigma_j \left(L_j - \langle L_j \rangle\right) |\psi\rangle\, dt.$$

This equation represents the evolution of the quantum vector state of a particle subject to a diffusion process. (The first term is just the usual Hamiltonian in the linear Schrödinger equation, the other two terms account for random diffusion and interaction with a larger environment). It is obvious that the mathematical nature of both source and target demand some mathematical competence and a good deal of knowledge of quantum mechanics in order to be able to infer anything at all from this equation! Conversely, a

detailed study[40] of the inferential capacities of this equation suggests that the representational source of a measurement process on a completely open quantum system is given by: $|d\psi\rangle = - \frac{1}{2} L_j^2 |\psi\rangle dt + L_j |\psi\rangle dt$. Having set the intended representational uses for the first equation, we are led by an investigation of its ability to allow inference regarding quantum processes, to accept the force of the second equation points to a measurement on an open system. This search for a dynamical equilibrium between i) and ii) seems to constitute a typical pattern of scientific representational activity.

[inf]'s part (ii) has the important function of contributing the *objectivity* that characterises scientific representation. In contrast to part (i), it in no way depends on an agent's existence or activity. It requires A to have the internal structure that allows agent and informed agents to correctly draw inferences about B, but it does not require that there be any agents who actually do so.[41] And this turns out to be exactly the feature that distinguishes cases of objective scientific representation (however inaccurate) from arbitrary stipulation. The quantum state diffusion equation has the resources to allow a competent and informed user to draw inferences concerning the state of a quantum particle subject to a localisation procedure. These are not inferences that a competent agent could derive on the basis of any odd equation: they are specific to the chosen source/target pair. On the other hand, the equation does not allow an agent, no matter how competent or informed, to draw any specific inferences (that is, inferences that could not have been derived on the basis of a consideration of any other equation, or any other object for that matter) about someone's mental or cognitive states, or a process of nuclear fission. Consideration of a graph of the Forth Rail Bridge does not lead an agent to any reliable conclusions regarding the city of Edinburgh (i.e. conclusions that could not have been derived on the basis of a consideration of any other object). [42]

10. Arguments in Favour of the Inferential Conception

However minimalistic and deflationary, this inferential conception of representation meets all the demands on a satisfactory theory of representation.

i) It avoids the *variety*, *logical*, *misrepresentation*, *non-sufficiency* and *non-necessity* arguments.

The *argument from variety* is avoided by construction, since [inf] does not require any specific means of representation, it just requires that there be some means or other. Thus

[40] See Percival, 1999, chapters 2,3,4,5.
[41] Note that "correctly drawing inferences" is not equivalent to "drawing inferences to true conclusions". A photograph showing me enthusiastically waving the Union Jack in a crowd at the Queen's parade may lead an informed and competent inquirer to infer the false conclusion that I am British. The normative standards of correctness required by [inf] are inferential merely, and do not depend on the truth or otherwise of premises or conclusions.
[42] Emblems, like ordinary names, are often more than mere arbitrary stipulations. The history of an emblem, the choice of a name, often reveals meaningful information about the object or person denoted. This means that in practice emblems, and names, are not mere denoting signs, but also play a connotative function, and can too exhibit the *objectivity* of scientific representations.

all instances of scientific representation will meet [inf] no matter what specific means (similarity, isomorphism, truth, etc) they employ.

[inf] has the logical properties of representation: it is non-reflexive, non-symmetric and non-transitive. It does not follow from the fact that the representational force of A points to B that it must also point to A itself; nor does it follow that the force of B (if it has any) points to A. The graph's force points towards the Forth Road Bridge, not towards the graph itself, and the bridge's force at best points towards the city, not towards the graph. Transitivity fails too in general since it does not follow from the fact that A's force points to B, and B's force points to C, that A's force *also* points to C. The graph's representational force points to the bridge, the bridge is an emblem of the city, but the graph's force does not henceforth point towards the city. Hence the *logical argument* is avoided.

The *misrepresentation argument* comes in two forms: inaccuracy and mistargetting. Part (i) of the inferential conception takes care of mistargetting, by explicitly bringing in the notion of force into the definition of representation. Part (ii) of this conception accounts for inaccuracy since it demands that we correctly draw inferences from the source about the target but it does not demand that the conclusions of these inferences be all true, nor that all truths about the target may be inferred.

The *non-sufficiency argument* is doubly taken care of. On the one hand, the inferential conception is deflationary and does not lay down a sufficient condition for representation. In every specific context of inquiry, given a putative target and source, a stronger condition will be met; but specifically which one will vary from case to case: In some cases it will be isomorphism, in other cases it will be similarity, etc. *Once* these specifications have been met in any concrete case, the inferential conception will still avoid the non-sufficiency argument. This argument turns on the ubiquiticity of the phenomenon of mistargetting, while [inf]'s part (i) explicitly requires the source's force to point out the true target of the representation.

The inferential conception lays down two necessary conditions on scientific representation. [inf]'s part (i) is necessary for any kind of representation, while part (ii) minimally distinguishes scientific and iconic representation from mere denotation or arbitrary stipulation. The *non-necessity argument* trades on inaccuracy, but [inf]'s part (ii) only requires strict normative criteria of *inference* – it does not require the truth or approximate truth of the conclusions derived about the target of the representation. Hence the argument is avoided.

ii) It accommodates the impossibility to distinguish in practice between the means and constituents of representation.

On the inferential conception the only constituent of scientific representation is the fact that it possesses means; the only property a source A and a target B must share is the holding of some means-relation from A to B. This deflationary assumption is built into [inf] in two stages: part (ii) asserts that the source has the resources to stand in some

representational means-relation to the target; part (i) asserts that as a matter of fact it does. Hence [inf] is fulfilled as soon as we are able – by whatever means – to draw inferences regarding a target on the basis of reasoning about a source. The particular process of reasoning and inference that we carry out *ipso facto* instantiates the constituents of representation. It is hardly surprising that the constituents of representation can not be distinguished in practice from its means!

iii) It explains how isomorphism and similarity, among others, are appropriate means of representation in their respective domains.

[inf] denies that scientific representation is constituted by truth, empirical adequacy, isomorphism or similarity; yet it explains well why these notions may be adequate *means* for representation in their appropriate domains. Truth, empirical adequacy, isomorphism and similarity all have the property of allowing us to draw inferences regarding target systems. If any of these relations obtains between a putative source and a putative target then part (ii) of [inf] is satisfied. For instance, the discovery of an isomorphism between two particular structures amounts to the discovery that these structures might stand in a representational relation, since the appropriate means obtains that would enable an agent to infer features of the one on the basis of reasoning about the other.[43] The inferential conception is instantiated as soon as an agent makes use of the isomorphism in order to infer features of the target-structure on the basis of reasoning about the source-structure. Isomorphism is in that case the concrete means that allows us to draw the required inferences. Mutatis mutandis for truth, empirical adequacy and similarity.

11. The Many Virtues of Inferentialism

I have assumed throughout that it is not required for a satisfactory theory of representation to shed light on representational accuracy, empirical adequacy, or truth. However, the inferential conception has the added virtue to explain these three notions as follows: A representational source licenses inferences regarding its target. The representation is true if it licenses no inferences to false conclusions about the target; it is empirically adequate if it licenses no inferences to false conclusions about the observable or measurable aspects of the target; and it is accurate if it is true and complete, licensing inferences to true conclusions about every aspect of the target. It is important to emphasise that neither “true” nor “accurate” are on this conception of representation equivalent to “mirror”: the source may be as different and dissimilar from the target as it could be, and still licence true conclusions. The QSD equation is not a mirror image of the state’s motion in Hilbert space, but it arguably licenses true conclusions about it.

But then neither is artistic representation a case of mirroring. Indeed if the inferential conception is right, scientific representation is in several respects very close to iconic modes of representation, like painting. Representational paintings, such as Velázquez’s

[43] It does not however amount to the discovery that one structure represents the other. That requires part (i) of [inf] to be satisfied too, which demands the additional discovery that the representational force of one of the structures points towards the other.

portrait of Innocent X permit us to draw inferences regarding those objects that they represent. The Velázquez canvass allows us to infer some personal qualities of the Pope and some of the properties of the Catholic Church as a social institution, as well as the Pope's physical appearance. But the drawing of these inferences requires a fair amount of knowledge about the social and historical context in which the painting came to be produced. This illustrates an important advantage of [inf] over its competitors, including the DDI model: It is a familiar experience, in the presence of a canvass, to feel that one is not in the epistemic position to be able to draw some of the relevant inferences, yet to be simultaneously aware of the representational character of the canvass. The painting is representational for us too, even if we do not carry out the inferences, since we appreciate that it possesses representational force.

In fact a remarkable and important virtue of the inferential conception is its ability to capture the representational / non-representational distinction in art as well as science. Its application to abstract art cuts roughly at the same place as Wollheim's (1985) "seeing-in" theory. On both accounts much abstract art, including certainly most surrealist and cubist art, turn out to be fully representational. There are similarly fuzzy cases on both accounts, such as Rothko's paintings, which the artist himself claimed to represent the Holocaust, but whose force is opaque to even the most informed and competent interpreters. Cases of unambiguously non-representational art turn out to be few; Mondriaan's *Diagonal Compositions* – which Mondriaan himself explicitly claimed to be "non-objectivist" – may be uniquely exemplary in this regard. [44]

One final virtue of the inferential conception is its ability to deal with cases of incompetent use, cognitive dissonance, or imperfect information on the part of the agent. A untrained, incapable or insufficiently informed agent would be unable to correctly apply the QSD equation: we are not thereby inclined to withdraw the claim that the equation actually represents quantum measurements, perhaps even that it represents them accurately. As an illustration of imperfect information consider Einstein's introduction of the cosmological constant into his GTR field equations, on the assumption of a static universe. The original GTR equations represented all along, of course, even when Einstein was mistakenly led to believe they didn't. (There may be yet another turn of the screw to this story, since it is now argued that new evidence suggests that the constant will have to be re-introduced!) [45]

Incompetent use, cognitive dissonance or imperfect information may cause agents to incorrectly draw inferences from a source about an intended target, or to draw them about the mistaken target; and perhaps to wrongly decide on the basis of such mistaken inferences that the representation is not accurate, or not a representation at all. The inferential conception explains well how this can happen: the source's representational

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[44] Rothko's paintings, like Picasso's *Guernica*, raise the interesting issue of whether the objective representational force of a painting is always transparent to the artist, and if so whether it necessarily dovetails with the artist's own conscious intended interpretation. I agree with Baxandall (1985) that it makes methodological sense to presume that the answer is positive in general, but I also agree with Blunt (1969) that there are cases where this need not be so.

[45] Gamow recounts that Einstein came to regard the introduction of the cosmological constant as his "biggest blunder". (1970, p. 44). John Earman (2001) provides a good historical overview.

force points towards the target; and the source has the resources to allow a competent and informed user to draw inferences regarding the target – it just so happens that these resources are not employed appropriately by the agent. Hence the source appears to be faulty as a representation, or no representation at all; when as a matter of fact the fault lies entirely with the agent. On the inferential conception, scientific representation, unlike linguistic reference, is not a matter of arbitrary stipulation by an agent, but requires the correct application of functional cognitive powers (valid reasoning) by means that are objectively appropriate to the tasks at hand (i.e. by models that are inferentially suited to their targets).

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