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Two senses of representation in science

(Dos sentidos de representación en ciencia)

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ABSTRACT: Accounts of scientific representation typically assume that there is a single sense of "represent", and they attempt to develop a theory that can account for all its features. The aim of this article is to draw the consequences of a distinction between two senses of "represent" that has been proposed recently. Taking inspiration from the distinction between speaker-meaning and expression-meaning in philosophy of language, a first sense is analysed in terms of the mental states of the user of a vehicle in context, and a second sense in terms of communal norms constraining contextual uses. I argue that making this distinction, and thus understanding the representation relation as essentially indexical and normative, can help us move beyond the controversies between various accounts of scientific representation, notably what have been dubbed informational and functional accounts, as well as debates regarding the ontology of scientific models.

KEYWORDS: scientific representation, norms, indexicality, ontology of scientific models.

RESUMEN: *Las teorías de la representación científica típicamente asumen que hay un único sentido de «representar», y tratan de desarrollar una propuesta que dé cuenta de todas sus características. El objetivo de este artículo es extraer las consecuencias de una distinción entre dos sentidos de «representar» propuestos recientemente. Inspirándose en la distinción en filosofía del lenguaje entre significado del hablante y significado de las expresiones, se analiza un primer sentido en términos de los estados mentales del usuario de un vehículo representacional en un contexto, y un segundo sentido en términos de normas comunitarias que restringen usos contextuales. Defiendo que trazar esta distinción, y por tanto entender la relación de representación como esencialmente indéxica y normativa, puede ayudarnos a superar controversias entre diferentes teorías de la representación científica, especialmente las conocidas como teorías informacionales y funcionales, así como debates acerca de la ontología de los modelos científicos.*

PALABRAS CLAVE: representación científica, normas, indexicalidad, ontología de los modelos científicos.

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1. Introduction

Philosophers have been debating in recent decades about what constitutes scientific representation, that is, what makes a source of representation in science, typically a model, a representation of its target. This question can be phrased using the more general category of *epistemic representation*. An epistemic representation, such as a map, is a representation whose main function is to allow its users to acquire knowledge about a particular target system. The question is then: what makes an epistemic representation a representation of its target? Philosophers traditionally answered this question by appealing to substantive relations between sources and targets of representation, such as similarity, but many authors have argued that we should focus instead on the functional role played by representational vehicles for their users, and understand representation not as a two-place relation, but as a three-place relation between a user, a vehicle and a target system (Giere 2010; van Fraassen 2008; Bailer-Jones 2003; Suárez 2003). Following Chakravartty (2010), I will refer to these two approaches as *informational* and *functional* theories of representation respectively.

In response to difficulties faced by some functional theories, I have recently suggested that there are actually two different meanings of "represent": the term can refer either to the way a representation is actually used in context, or to how it *should* be used according to the norms of our epistemic community (Ruyant 2021). This division is a direct transposition of Grice's notions of speaker-meaning and expression-meaning from linguistic to epistemic representation. One consequence of my account is that the now commonplace idea that representation is a three-place relation between user, vehicle and target system is only true for one sense of representation (contextual use). In the other sense (communal status), which is, arguably, more prominent, representation is better understood as a three-place relation between an *epistemic community*, a *kind of structure* and a *kind of target*, and this relation is essentially normative.

I believe that this theory has potential far reaching implications beyond its original focus, for the general debate on the nature of representation and other related issues, notably the ontology of theoretical models (whether they should be construed as abstract, fictional or artefactual entities). These implications for the larger debate were not examined in (Ruyant 2021). The aim of this paper is to do so, and to argue in particular that adopting a distinction between two senses of "represent" can help us move beyond the controversies surrounding these debates. I will argue that these controversies trade on an ambiguity between the two senses of representation, because each brings about diverging intuitions and calls for different answers regarding what is a model, a target system, and what constitutes the representation relation. Acknowledging the distinction and articulating its two components within a normative theory of representation allows us to take the benefits of competing accounts without having the same limitations.

I first briefly present the distinction itself in section 2. Then I review the debates on what constitutes the representation relation in section 3, and on the ontology of models and target systems in section 4, each time explaining how the distinction helps us move forward in these debates.

2. The Two Senses of Representation

2.1. Contextual Representational Use

Grice famously introduced a distinction between speaker meaning and expression meaning. The former has to do with speakers' intentions when uttering sentences: according to Grice, what a speaker means by uttering a sentence can be analysed in terms of the beliefs or thoughts that she or he overtly intends to convey to an audience. Speaker-meaning is typically informed by the context. Expression-meaning, on the other hand, corresponds to the "timeless" meaning of a given expression or sentence in a language: what this sentence means *in general*, sometimes simply referred to as *linguistic meaning*. Grice thinks that speaker-meaning is more basic, in that expression-meaning is analysed in terms of it, namely in terms of norms or values concerning the appropriate use of sentences for conveying beliefs in a linguistic community. (Grice 1989 ch. 18) On the contrary, even though speakers would typically rely on linguistic norms in order to communicate efficiently, speaker-meaning can be analysed in terms of their intentions only, without reference to expression-meaning. The theory thus provides an illuminating connection between linguistic meaning and linguistic use without strictly identifying one with the other.

In this section, I briefly flesh out a transposition of this theory of meaning to epistemic representation that follows my proposal in (Ruyant 2021), and that serves the same broad purpose as Grice's. I will not attempt to motivate every detail of this theory of representation, but only present a version of it for the sake of showing its impact on the debates.

Let us start with the notion of contextual representational use, which is the analogue of speaker-meaning: this is the basic notion on which the communal sense of representation will be built.

A concrete epistemic context is one where an agent or group of agents wants to learn something about a concrete object or system. For example, someone might want to know how many metro stations there are between the university and the opera, or if the pendulum she is looking at would oscillate more than three times in a second if it were heavier. We have an instance of *epistemic representational use* if the agent uses a vehicle (a metro map, Newtonian equations written on paper, etc.) in order to acquire this knowledge. They would typically manipulate the vehicle, and then interpret the result of these manipulations in terms of the intended target system so as to generate beliefs about this system, all this by following specific rules. This could be, for example, counting circles along a line on a metro map and interpreting the result as an actual number of metro stations, manipulating equations on paper whose symbols are taken to refer to the properties of a concrete pendulum, or pouring water in a scale model of a bay or interacting with a computer program and interpreting the observed results in terms of water levels at various locations in a given scenario.

Here is a definition of representational use adapted from (Ruyant 2021):[1]

> **Contextual Representational Use**
>
> *A* uses a concrete vehicle *V* with demonstration and interpretation rules[2] *R* to represent a concrete system *O* if and only if *A* uses *R* on *V* in order to generate beliefs about *O*, and *A* accepts that doing so is a reliable means of producing knowledge about *O*.

This definition assumes that both the vehicle and target of representation are concrete entities. This aspect was not really discussed in (Ruyant 2021). The thesis that I would like to

[1] The adaptation roughly consists in casting the definition in terms of belief production in particular instead of goal achievement in general. I think that this restriction makes the definition more simple and intuitive. However, it will not matter much for the rest of the paper.

[2] These terms are borrowed from Hughes (1997).

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put forth here is that this kind of use, where only concrete objects are involved, is the most primitive kind of representational activity, and that more abstract activities can either be considered derivative or be reinterpreted in terms of concrete representation. More precisely, I believe that using an abstract entity, such as a mathematical structure, in order to represent something is really using a concrete entity and demonstration rules that together instantiate this abstract structure, and that representing an abstract entity, such as a kind, involves *imagining* representing a concrete instance of it in order to derive general or hypothetical conclusions (which is also what representing a fictional entity amounts to). This will become relevant in section 4, where we will be concerned with ontological questions.

It is essential to epistemic representational use that the vehicle and rules generate beliefs about the intended target. So, for example, exploring the structure of a scientific model for the sake of it does not count as epistemic use. At most, it could count as inquiring about what epistemic uses are afforded by the model. It should also be noted that the beliefs generated by the representation need not be true nor justified by anything other than their compliance with the rules accepted by the agents. All that is required is that users assume or pretend (for the sake of an experimental test for instance) that the vehicle and rules are a reliable means of acquiring knowledge. So, if a superstitious agent interprets patterns in coffee grounds in terms of lottery results, using interpretation rules just invented on this occasion, then the coffee grounds are used as an epistemic representation of lottery results. In this sense, representational use is not constrained by any form of similarity between the vehicle and target, nor by anything external to the agents: it reduces to the mental states of the agents.

2.2. Communal Representational Status

This definition of representational use could raise suspicion if it were understood as a complete account of epistemic representation. The problem is that epistemic vehicles are often attributed a representational status independently of any particular use.

Imagine that someone is using a map of Mexico City in order to navigate New York City, and that she is lucky enough to successfully reach her destination. This person is using a vehicle with interpretation rules in order to form beliefs about the configuration of New York City, and she (wrongly) accepts that the vehicle interpreted as such is reliable. So, according to our definition, the map that this person is holding represents New York City. This result seems wrong: we just said that it was a map of Mexico City, so it represents Mexico City, *not* New York City. However, the contradiction disappears if we distinguish between two senses of representation: the map represents$_1$ New York City (for its user) because it is being used to navigate New York City, but it represents$_2$ Mexico City (in general) because it should *normally* be used to navigate Mexico City[3]. When I say "normally", I don't mean that people often use this map to navigate Mexico City, but that this is the *appropriate* way of using it. This use is *licensed* by our epistemic community. This is our second sense of representation, and this is what is usually meant when we say that

[3] The linguistic analogue would be using a word incorrectly, for example using "moth" to refer to a butterfly: then speaker-meaning and expression-meaning come apart.

something (a model) represents something else (an object) in full generality (as opposed to when we say that someone is using something to represent something else).

An important aspect of communal licensing is that it does not, in general, concern concrete objects. If I write down Newtonian equations corresponding to the model of the Simple Pendulum in order to predict the oscillation period of my grandmother's clock, then this use is appropriate (or not) in virtue of instantiating specific *kinds* of vehicle, demonstration and interpretation rules and target system, but the particular objects involved do not actually matter. In this context, what is licensed is the model of the Simple Pendulum (an abstract structure) as a representation of pendulums in general (a kind), and my markings, the rules that I am using and my grandmother's clock are considered appropriate merely to the extent that they instantiate them. After all, no physicist has ever checked whether my markings correspond to this model, or whether their interpretation in terms of the clock is appropriate.

I analyse in (Ruyant 2021) the relation between kinds of uses and their instances in terms of indexicality. A linguistic entity is indexical if its content (reference or truth conditions) varies from context to context. Its linguistic meaning can be analysed as a *character*, which is a function from context to content (Kaplan 1989). For example, the content of "I am hungry" varies depending on who utters it, and its character can be analysed as a function that associates to each context the proposition that the speaker in this context is hungry. The same would go for epistemic representations, and in particular for associated rules of demonstration and interpretation: their reference would vary from context to context, simply because they apply to different concrete vehicles being used to represent different systems of the same kind in different contexts.[4] Typically, the symbols of a scientific model such as the model of the Simple Pendulum would implicitly be associated with a character (function from context to content) that says how they ought to be interpreted: "l refers to the length of the string; $x(t)$ refers to the position of the pendulum relative to its rest position along the axis of oscillations at time t, etc.". This character need not be made explicit in practice: perhaps it partly rests on the tacit knowledge of competent model users, but a representational use is licensed in so far as the rules that are used in context correspond to it.

An implication of this view is that in general, epistemic vehicles do not refer to anything outside of concrete uses. They do not represent an object, but a *kind* with various possible instances. We often hear scientists say that a model represents *a* pendulum, *the* hydrogen atom or *prey-predator systems*. These locutions should be interpreted as generics, just as when we say "a triangle has three sides", "the dodo is extinct" or "tigers are striped": we are not talking about a particular triangle, dodo or group of tigers, but about a *kind*.[5] There are exceptions to this: city maps or the Copernican model of the solar system represent one particular object in the world, but for the sake of simplicity, we can assume that they represent a kind which only has one instance. At least in science, it does not seem that direct reference to individual objects plays a fundamental epistemic role anyway: for ex-

[4] Note that this is not a reference to the notion of *essential* indexicality, which has been employed by van Fraassen (2008) in relation with self-location and centred beliefs, but to something more mundane.

[5] This means that the representation relation can depend on the semantics of kind terms. However, I will not assume any particular theory of reference for kind terms here: I delegate this issue to the philosophy of language. In any case, scientific models do more than simply referring to a kind, and they often represent complex configurations rather than instances of natural kinds.

ample, astrophysicists hope that the standard model of the Sun (also called the spherically symmetric quasi-static model of a star), generalises to other stars and allows us to learn about them (Turck-Chièze 2016).

Taking stock, here is our second definition, also adapted from (Ruyant 2021)[6].

> **Communal Representational Status**
> A kind of structure S with indexical demonstration and interpretation rules I represents a kind of system K in an epistemic community E if and only if it is considered appropriate in E, in any context $C = \{V, O\}$, to use rules $R = I\,(C)$ on a concrete vehicle V instantiating S in order to represent an instance O of kind K.

For example: that the Lotka-Volterra model (a kind of mathematical structure with indexical rules of interpretation associated with its symbols) represents prey-predator systems just means that it is considered appropriate in the scientific community to use concrete equations and rules instantiating the model in order to represent a concrete prey-predator system.

This definition concerns representation of a kind of system by means of a kind of structure, but by extension, we can say that concrete instances represent or are represented (or representable) if their kinds represent or are represented in this sense. I presume that what indicates that we are using "represent" in the communal rather than contextual sense is not the abstractness of sources and targets, but rather the fact that no reference to specific users or contexts is made.

The notion of a structure employed in this definition is meant to make clear that what is licensed is a set of constraints on our inferences: the structure, with its associated demonstration rules, is the bearer of these constraints. In some cases, these constraints are purely mathematical or deductive, but in other cases, notably with computer simulations and scale models, the constraints on our inferences are partly supported by causal processes, such as water flow or electronic computations, in which cases the structure is causal. The fact that what is licensed, according to our definition, is a *kind* of structure leaves room for characterisations of this type.[7]

To sum up, our first, basic definition explicates the function of epistemic representation for agents in context. It is expressed in terms of the mental states of these agents. Our second definition explicates what it means for a vehicle to represent an object in general. It is cast in terms of communal norms constraining contextual use, and therefore depends on the first definition. The former sense of representation makes it a three-place relation between users, vehicle (with rules) and target, while in the latter sense, representation is also a three-place relation, but this time between an epistemic community, a kind of structure (with indexical rules) and a kind of target.

2.3. Norms and Communities

I introduced this two-level analysis of representation in (Ruyant 2021) in order to improve on the minimalist account of Callender and Cohen (2006), which was criticised, among

[6] The adaptation follows the one of the previous definition, plus a mention of *kinds* of structure instead of structure simpliciter that is explained below: see next footnote.

[7] This is an improvement on (Ruyant 2021)'s definition, where S is only characterised as an abstract structure, which would imply that scale models are not licensed qua *physical* structure for example.

other things, for wrongfully implying that "anything goes" when it comes to what represents what in science. According to the present account, this is not true: there are communal norms regarding representation vehicles and their targets. This normative aspect is, arguably, the main novelty of this theory of representation. Note, however, that the theory does not tell us what makes a representational use appropriate in a community.

In mundane contexts, like when I quickly draw a map to tell you how to come to my home, we could suspect that norms of appropriate use are determined by the author of the representation, by mere stipulation. But things might not be so easy in science. For something to count as an appropriate representation of something else in the scientific community, it must be incorporated in the scientific corpus, and for this, it must probably be sufficiently robust, explanatory and coherent with well accepted theories, or, more generally, comply with the aims and values of science. As for the rules of interpretation for these representations, they might be associated with experimental norms and methods of operationalisation that warrant stability and reproducibility in concrete applications and perhaps follow other criteria. On this view, scientists are mainly in the business of developing, assessing and transmitting norms of representation. But their selection criteria might vary from one field to another or from one research community to another. Furthermore, there are epistemic representations outside of science that these definitions aim at capturing as well, including in mundane contexts. This is therefore an advantage of this account that it does not assume any specific criteria of appropriateness.

In any case, it is important to remember that the criteria of selection for vehicles of representation are *not* constitutive. Markings on paper do not become a map of Mexico City simply in virtue of being reliable for navigating this city. What really *constitutes* representation is the fact that there is a norm of use; the reliability of the representation at most *explains* why such a norm came about. A map can be entirely unreliable, but still a map if it is licensed as such within a community.

This account is deflationary in spirit, and perhaps one could have the following worries: how can mere scientific norms of representation provide *understanding* about the world, as scientific models arguably do? Or: how is this idea that models never really represent concrete entities outside of a context of use compatible with a minimal form of scientific realism, according to which science is concerned with a reality that exists independently of our activities?

I think that these worries are unfounded, and that the present account is largely independent of these issues. A scientific realist can claim that even if a model of protein only refers in context, biologists are committed to the existence of proteins in *all* living organisms, because models representing proteins are in principle applicable to any living organism (these uses are licensed), and they *would* refer if applied. A non-realist could be more reticent to make this inference. But the indexicality of models does not favour realism nor non-realism: at best, it helps identify the ampliative inferences that are accepted or rejected by defenders of various philosophical positions. As for the notion of understanding, it is important that the norms conveyed by scientific models are *epistemic*: they tell us what knowledge could be acquired in any situation of a given kind, which is a form of understanding concerning the common features of these situations. This is at least compatible with unification theories of scientific understanding (Kitcher 1989), according to which understanding has to do with allowing the same derivation patterns to be applied in various circumstances.

Let us now see how this theory of representation sheds light on various debates, starting with the model-target relationship.

3. *The Model-Target Relationship*

3.1. Functional and informational theories of representation

Debates concerning the representation relation are divided between authors who put emphasis on substantive relations between vehicles and models, and other authors who prefer to focus on the function of models for their users: what Chakravartty (2010) has called *informational* and *functional* theories of scientific representation respectively. Let us present these theories and their difficulties in turn.

Representational vehicles, in particular pictorial representations, are often similar in relevant respects to what they represent. This could prompt the intuition that epistemic vehicles exert their epistemic function in virtue of their similarity to the represented object: they are "copies" of their target that allows us to gain knowledge about the target. We could say that *S* represents *T* if and only if *S* is similar to *T* in relevant ways (Giere 1988). A related idea is that *S* represents *T* if there is an isomorphism, a partial isomorphism or a homomorphism between *S* and *T* (van Fraassen 1989; da Costa and French 2003; Bartels 2006). Morphisms can be seen as mathematical or structural similarities, so I will not distinguish them in what follows.

A first objection against informational theories is that similarity is not sufficient for representation, in particular because it lacks directionality (Suárez 2003). Many things are similar or isomorphic in many ways without being representations of each other. We can address this issue by allowing the users of the representation to pick the relevant similarity relation. However, a second objection is that similarity is not necessary either, because it is possible to *misrepresent* something, that is, to represent it inaccurately. In such cases, there is no perfect similarity between the relevant properties of the source and target, but the vehicle is still a (bad) representation of its target. Proponents of informational theories seem to mistake criteria of good representations for criteria for being a representation simpliciter.

In response, some authors have claimed that this is not a mistake, because representation is a success-term, or a "thick" term, both evaluative and descriptive. Being a representation would imply being a *good* representation (Poznic 2018; Chakravartty 2010, 209-10). If this is the case, then some kind of similarity is actually required for representation.

I do not think that this proposal makes much sense. "Cruel" is a thick term, and one can be more or less cruel, or *truly* cruel, but can a model be *truly* a representation of something? Would we say that the Ptolemaic model is *less* a representation of the solar system than the Copernican model? Does "bad representation" sound like as much of an oxymoron as "good cruelty"? I believe not. Now, as Chakravartty (2010) notes, philosophers are free to regiment language as they wish if they find it useful. But thin usage of the word "representation" seems much more useful in so far as it allows the evaluative and descriptive components of epistemic practices to be kept apart for analysis. So, there is no good reason to assume that similarity is required for representation.

These difficulties to account for misrepresentation have motivated opting for functional accounts of representation instead of informational ones, that is, focusing on the role played by representations for their users instead of looking for some substantial source–target relationship. A common trend in this respect consists in relying exclusively on the mental states of model users (their beliefs, goals, etc.) in order to understand what representation is. Similarity can still be involved, but as a postulate from users rather than as an actual relation between sources and targets (Giere 2010; Weisberg 2013). This strategy has been dubbed "General Griceanism" in reference to Grice's analysis of speaker meaning (Frigg and Nguyen 2020 ch. 2) (although the distinction between speaker-meaning and expression-meaning is never mentioned in this literature, apart from (Ruyant 2021)), and indeed, it has become commonplace to assume that representation is (at least) a three-place relation between a source, a target and a user.

An early account along these lines is Hughes (1997)'s DDI account. According to Hughes, representing is using demonstration rules and interpreting their results in terms of a target system denoted by the model (this is very close to the notion of contextual use from section 2.1). Callender and Cohen (2006), already mentioned, have also suggested a minimalist Gricean account of representation. According to them, that *A* represents *B* only requires that an agent stipulates that this is so. Contessa (2007) has proposed an inferentialist account in terms of *interpretation*, which is a denotation relation between specific properties, relations and functions of the model and target. Other accounts that are similar in spirit are Frigg and Nguyen (2020)'s DEKI account (which is more sophisticated, in order to allow for targetless models) and Weisberg (2013)'s account, based on the notion of a construal and on a postulated similarity. Admittedly, some authors also consider communal aspects in their analysis (e.g. Weisberg 2013, 76-77), but generally, this is only to the extent that they shape the mental states of individual scientists, and priority is given to these mental states for establishing the representation relation.

I think that Griceanism, so understood, is problematic. Against such views, and in order to parallel the previous discussion on similarity views, it is easy to show that the intentions of model users are neither necessary nor sufficient for a model to represent something.

User intentions are not necessary because a model, or a picture for that matter, is still a representation of its object even if no one is actually using it nor entertaining mental attitudes towards it (this was noted by Suárez (2004) in his discussion of Hughes's account). A map of Mexico City that stays in my pocket is still a map of Mexico City. The Mona Lisa still represents Lisa Gherardini when the Louvre is closed. Bohr's model of the atom is still a representation of an atom even if no one is using this model anymore. The intentions of the creators of the representation might matter sometimes, but arguably, they are not necessary either: Volterra initially developed his prey-predator model as a representation of fish population in the Adriatic Sea, referring to Lotka's equations that were first proposed in chemistry, but now the model is widely taken to be a model of prey-predator systems in general.

This aspect could be accommodated by invoking latent beliefs from potential users in place of actual intentional states. Admittedly, a reduction to mental states is not necessarily a reduction to actual uses of a vehicle. However, even if we succeeded in showing that latent intentions are necessary, a further problem is that user intentions or beliefs are not sufficient for representation, because of the possibility of *misuse*, which parallels the possibility of misrepresentation for similarity-based accounts. What I call misusing is using *A* to represent *B* when *A* is not actually a representation of *B*. If the previous sentence makes sense, then misuse is possible.

An example of this is using a map of Mexico City in order to navigate New York city. Another illustration of misuse is given by Contessa. He claims that any interpretation of a model in terms of a target is sufficient for representation, and that, for example, it is possible to "retarget" Rutherford's model of the atom in order to represent a hockey puck sliding on ice. According to him, although inaccurate, the model would count as a representation of the puck. The reason for this liberal stance is that Contessa cannot see any other "mysterious ingredient" that could be involved in representation. However, Rutherford's model is not the representation of a hockey puck, but of an atom, so it is a case of misuse. Bolinska (2013) also sees a problem in Contessa's liberal stance, and suggests adding that the user must "aim at faithful representation". However, faithfulness is not always enough to avoid misuse.

The upshot is that there are constraints on what can represent what in science: it is not up to users to decide. This is the main problem with Gricean accounts, and a common complaint from defenders of informational theories against them (see for example (Bueno and French 2011)). Boesch (2017) is right to argue (against Callender and Cohen) that in order to know what a model represents, one has to examine its history: how and why it was constructed, how it was received by the scientific community and how it is currently used. Scientific representations are *licensed* by scientific practice: this is Contessa's "mysterious ingredient", and it shows that user intentions are neither necessary nor sufficient for something to represent something else.

3.2. How distinguishing two senses sheds light on the debate

We have seen two opposite approaches towards scientific representation, each with their problems: on the one hand, informational theories fail to account for the possibility of misrepresentation, and on the other hand, "Gricean" theories fail to account for the possibility of misuse. My diagnosis is that each family of theory focuses on only one of the two senses of "represent" and ignore the other, while both are needed in order to fully understand scientific representation. This is how our account allows us to move forward in the debate.

Informational theories attempt to characterise what makes a vehicle a representation of its object in general, independently of the context and of idiosyncratic user intentions. In this sense, they can be seen as focused on the communal sense of representation: from the perspective of our account, what they attempt to do is make explicit the norms of epistemic (or scientific) representation. I think that this is the right focus, because this sense of representation is generally more prominent, and informational theories are entirely right that particular users or contextual aspects are irrelevant in this respect. However, these theories err in thinking of these norms as absolutely necessary conditions for representation, independently of the community in which they take place, as if contextual representation derived from a pre-established harmony between vehicles and their objects that did not depend on us. It is actually the other way around: norms of representation derive from representational uses. This is what the possibility of misrepresentation (which also applies at this communal level) demonstrates.

A way of making informational accounts of representation apparently compatible with our definition of communal status is the following. Remember that according to this definition, A is a representation of B in community E if it is licensed as such in E. Assume that we make explicit the criteria C used in community E to license their representations. Assume further that these criteria only depend on aspects of sources and targets of representation. Then we could say that *A* is an *E*-representation of *B* if it satisfies *C* (*A*, *B*). Replacing *E* with “scientific”, we would get a definition of scientific representation that only rests on characteristics of *A* and *B*. This looks like what informational theories are after, which would explain why these accounts are often dedicated to defining scientific representation in particular rather than epistemic representation in general. Furthermore, it can also explain where this idea that representation is a success term comes from: a representation can comply better or worse with the criteria for being a scientific representation. Saying that a model is more or less representational sounds odd, but saying that a representation is more or less scientific not so much.

Similarity seems to make sense in this context, because epistemic representations, such as city maps, are generally licensed by epistemic communities for their inferential reliability. It is plausible that in most cases, reliability rests on the fact that the structure of the vehicle of representation reflects the modal or extensional structure displayed by the relevant properties of targets. Such a similarity at least guarantees that inferences will lead to reliable conclusions. It could obtain either because vehicles are directly selected for their similarity with their targets, or because similarity is a by-product of the selection process.

However, this strategy for saving informational theories ultimately fails for various reasons. A first problem is that the criteria by which representations are selected in a community can explain why *A* became a representation of *B*, but they do not tell us *what it means* for *A* to be a representation of *B*. So, taking informational theories, so understood, to provide a *definition* of scientific or epistemic representation is misleading. Similarity, for instance, does not constitute representation. It is only a good *indicator* that something is a representation of something else. If I see a drawing that looks like a tree, I can infer that it is probably the representation of a tree, but this inference is fallible: it might actually be a representation of broccoli.

A second problem is that the criteria by which representations are selected in a community might not depend only on sources and targets of representation. Assume, for example, that scientists aim at similarity. Whether similarity holds could be fundamentally uncertain, in which case selection criteria *C* are a function of the information available to scientists, and of the likelihood of a similarity *from their perspective*, so the perspective of users cannot be dispensed with.

Finally, the risk of this strategy is to overlook the variety of criteria by which representations are licensed. A speculative model conveying interesting hypotheses about a kind of target might be considered scientific even though scientists are not sure that it really is informative. An idealised model could be favoured for its scope, at the expense of its actual similarity with target systems. A model could be licensed only because scientists are accustomed to it, or because its author is renowned. Our account of communal representational status does not make any assumption about licensing criteria. They can vary from one community to the other, or even within a community. A normative account that leaves open the criteria by which representations are licensed is more apt to do justice to the diversity of practice. And the fact that whether a model is accepted by the scientific community for particular uses can be a matter of degree can explain why it still makes sense to say that a model is “more or less” scientific, independently of its compliance with precise criteria.

In contrast with informational theories, “Gricean” theories of representation rightly acknowledge that epistemic representation cannot be fully understood if we do not understand how vehicles are used to represent. They thus avoid the problem of misrepresentation. These accounts can be seen as valuable contributions to our understanding of the *contextual sense* of representation. However, they are at best incomplete, because they neglect the centrality of the normative and communal dimension of representation: this is what the possibility of misuse demonstrates. Furthermore, they err when they try to mitigate the limitations induced by their exclusive focus on representational use by adding layers of complexity.

Contessa's account of interpretation, for instance, rightly entails that "anything goes" at the level of contextual use: anyone is free to use Rutherford's model to make inferences about a hockey puck. Without this liberal stance, it would be hard to understand how new representations are ever produced: are new scientific models non-representational until they have a history of reception and use by other members of the scientific community? But when asking what a scientific model is a representation of in general, it is its communal status that matters, and in this respect, it is not true that "anything goes". However, trying to capture these constraints at the level of use (in terms of faithfulness from users, or of similarity postulates made by users for instance) is a mistake, because these constraints are merely normative, and norms can be broken.

Not all user-centred accounts of representation are purely "Gricean", and Suárez's inferentialist account does not suffer from the same difficulties. According to Suárez (2004, 768-73), *A* represents *B* only if *A* has the capacity to lead competent and informed users to a consideration of *B*, and *A* allows these users to draw specific inferences regarding *B*. This account can be readily recovered from our definition of communal status assuming that a competent and informed user is one who is capable of following the representational norms of the epistemic community. These norms of use can indeed lead an agent to a consideration of the target and allow her to draw inferences about it (Suárez (2010) himself notes that "the representational target [...] must be established by the norms that govern the practice"). The benefit of our distinction between contextual use and communal status here is that it makes explicit the articulation between two distinct levels of analysis.

In sum, disentangling two senses of "represent" and articulating them in a normative theory of representation sheds new light on the controversy between functional and informational theories. We can understand why informational accounts are attractive in some respects, and functional accounts in other respects, but also why both approaches have their limitations: this is simply because they each focus on a specific sense of representation and ignore the other. In order to move beyond these debates, we need to acknowledge these two distinct levels of analysis and their articulation, and then we do not face any of these limitations.

4. *Questions of Ontology*

4.1. Models as abstracta or fictional concreta

We have been concerned so far with the question of what constitutes the representation relation. Let us now address issues that have to do with the nature of models and target systems in science. Such questions arise in relation to the first one because we want models to have the right kind of relation to targets of representation and to their users, and this must be allowed by their nature. Like in the previous section, I will first present the main families of positions in the debate, and then explain how the distinction between two senses of representation allows us to move forward.

Some scientific models are apparently concrete physical entities: for example, the scale model of the San Francisco Bay constructed by the U.S. Army Corps of Engineers, or Phillips Hydraulic Computer, a model of the economy constituted of tanks and pipes. Thinking of models, or vehicles of representation in general, as concrete objects makes it easy to understand how they can fulfil their function: we physically interact with the model, and then observe the result of these interactions so as to draw conclusions about the represented system. We establish a mapping between vehicle and target, for example taking some part of the model to refer to some part of the target (a circle on a map and a metro station, say). Perhaps this idea could be extended to computer simulations, if we take them to be concrete instances of a program running on a specific machine. However, it already seems less obvious: copying the program does not make for an entirely new model. Note, in this respect, that Phillips Hydraulic Computer also has several physical instances, so even the idea that physical models are concrete particulars rather than kinds is not as straightforward as it seems.

In any case, this view does not fit well with theoretical models. A Newtonian model of the solar system is generally presented by means of a set of equations, but there is not a unique way of describing the same model, so it cannot be identified with specific equations. For this reason, many authors take theoretical models to be abstract entities (Giere 1988), and often set-theoretical or mathematical structures (Suppe 1989; van Fraassen 1989). An advantage of this view is that it makes quite clear how models and theories are related.

A problem is that making sense of how theoretical models are used in this abstracta view is not as straightforward as with concrete entities. How could we interact with an abstract entity in order to reach conclusions if it has no causal power?

Problems of this kind concern mathematical objects in general, and they can be delegated to the philosophy of mathematics. More worrisome, however, is the fact that theoretical models are often presented by scientists as if they were describing concrete systems, not mere mathematical structures. A teacher presenting the model of the Simple Pendulum in a physics class will generally talk as if she were describing a real pendulum and will attribute concrete properties to it, such as a spacetime location in a reference frame or an oscillation period, even though no pendulum is actually present in the classroom. It is hard to make sense of this kind of discourse, which is very common in science (including in scientific papers), from the abstracta view. They seem to imply that theoretical models are actually *works of fiction*: they incite us to imagine nonexistent concrete systems, and indeed, the properties that are attributed to them are sometimes properties that no real system could have, such as being constituted of a dimensionless solid attached to a massless unstretchable string.

This is the conclusion drawn by many authors. According to Godfrey-Smith (2007, 735), models are "'imagined concrete things' —things that are imaginary or hypothetical but would be concrete if they were real". According to Frigg (2010), who takes inspiration from Walton's pretence approach to fictions in the philosophy of art, model descriptions are like the text of a novel: they are "props in the game of make-believe", or instructions that prescribe us to imagine certain things using "principles of generation". These fictional objects can then be used to represent real entities. This thesis has been called *indirect* fictionalism. According to *direct* fictionalism, on the other hand, instructions for imagination directly concern either fictional or actual objects (Toon 2012; Levy 2015). In the latter case, these "imaginative descriptions of real things" could be partially true, which would avoid the difficulty of making sense of a comparison between actual and fictional entities, a difficulty with Walton's non-realist approach.

Fictionalist views have been criticised for not explaining how models produce knowledge about their targets. More than pretence can be involved in representation, and according to Poznic (2016), these accounts do not give us a means of discerning between the propositions that are held true or false by modellers. Knuuttila (2017) argues that they lead to a problem of coordination between the imaginations of various scientists. In response, one could focus on the intersubjective principles of generation mentioned by fictionalists, but then it becomes unclear to what extent imagined objects have an added epistemic value, as opposed to a merely psychological one. Furthermore, many "principles of generation" go beyond our capacities for imagination, and require the use of computers (Weisberg 2013) (see Frigg and Nguyen (2020, ch. 6) for a review of the debates and some responses).

A clear advantage of fictionalism is that it makes good sense of how theoretical models relate to their users: they are manipulated in imagination, or as props for imagination. However, the way models are related to targets of representation is not always clear, at least in the indirect view: in what sense could an imaginary object *refer* to (or be *about*) another one? A solution for indirect fictionalism is to invoke two representation relations: one that relates model descriptions to a fictional target, and the other that relates this fictional object to the concrete entity that it represents. This solution also addresses the problem of targetless models that affects other views. Many scientific models represent entities that turn out not to exist, such as the luminous ether or a bridge that will never be built, or entities that are not even supposed to exist by the modeller, such as a four-sex population or a chessboard city. The problem is that these models apparently have content, but if denotation by users or similarity is a necessary condition for representation, and if denotation or similarity must concern an existing entity, then these models do not actually represent anything. This is not a problem for indirect fictionalism: Frigg and Nguyen (2020, ch. 7.3), for instance, introduce a distinction between *representing* something (having a content) and *being a representation of* something (having a referent), and it is possible for a model to represent something without being a representation of anything. However, this solution can seem a little bit ad hoc (these two locutions are synonymous in ordinary language), and invoking two representation relations brings complexity and slack to the account.

Finally, a problem that affects Gricean approaches more generally is that few scientific models represent only one particular object: most represent kinds. For example, the quantum model of the hydrogen atom does not represent one specific hydrogen atom, but hydrogen atoms *in general*. It is not clear how to make sense of it if we take fictional descriptions to be directly about the target of representation, as per direct fictionalism, or if we want to introduce a denotation relation between the fiction and the target, as per indirect fictionalism. It seems that we would have to assume that kinds exist qua entities in a platonic world, or that the model represent all actual and possible instances of the kind simultaneously (but not their collection of course), which would constitute a radical departure from Griceanism, since these infinite number of relations do not have any counterparts in the mental states of any user.

4.2. How distinguishing two senses sheds light on the debate

In sum, theoretical models are apparently not concrete objects, but viewing them as abstract entities makes it difficult to understand how they are often presented. If we consider them to be fictional concrete entities in order to solve this issue, then it is their epistemic value, in relation to the targets of representation, that becomes less clear or requires adding complexity to our theory.

I believe that these problems originate in the fact that thinking of representation in terms of contextual use or in terms of communal status drives divergent intuitions regarding the nature of vehicles and targets. If we are primarily interested in the activity of model users, we are likely to put emphasis on concreteness, which allows for direct manipulation, either in reality or in imagination. But if we are interested in what represents what in general, then focusing on kinds and structures becomes more natural. In this respect, and in light of the analyses from the previous section, it is no coincidence that authors defending the abstracta view also typically defend an informational theory of representation, while fictionalist authors generally opt for a Gricean approach.

It could seem that these two views are contradictory: scientific models are either concrete or abstract entities. However, they can be made compatible by assuming that each concern a different sense of representation: abstract entities have a normative status at the communal level, and their instances are used at the contextual level. Furthermore, if we properly limit their respective scope in this way, the problems that seem to affect each of these views appear to be non-issues.

We should not ask a conception of theoretical models as abstract structures to account for how models are handled or presented, for instance, because such a conception only concerns the normative level of representation. What matters is only that these abstract structures are associated with indexical rules of use. Then the fact that it is unclear how one could interact with an abstract entity, or compare it with a concrete one, becomes irrelevant: in the end, users interact with concrete entities (equations on paper for example) in a way that instantiates the licensed structure and rules of the abstract model (at most we could wonder how norms affect users, but this question is far from specific to the topic that concerns us).

The way the abstract structures and rules that constitute a model are usually presented to an audience in classrooms or in scientific papers falls within the scope of representational use. This is where fictionalism can step in: not as a general theory of scientific models and representation, but as an account of one particular kind of use. The idea is that in such contexts where a model is presented without any actual target of representation being present, a fiction is invoked, because the point is not to apply the model to a specific target system, as would be the case in an experimental context for instance, but rather to explain how the model applies in general. Sometimes, this representational use also allows one to draw general conclusions about all targets to which it would apply. We can take fictionalism to account for uses of this kind, where the target of representation (not the vehicle!) is fictional, in full compatibility with our definition of contextual use from section 2. However, this does not correspond to the final aim of modelling activities, and so, we should not expect fictionalism to explain how the imaginary target involved in such uses is related to other concrete targets of the same model. This relation between various targets of the same model is captured at the normative / communal level, not at the level of contextual use.

There is no need to add layers of complexity, such as denotation relations between fictions and concrete targets, in order to account for the epistemic value of models or to discern between the propositions that are held true or false by modellers, in so far as fictionalism is not taken to be a complete account of representation in general, but only a description of a special (albeit prominent) use case.

In support of this interpretation, note that it is very common to invoke a fictional situation when devising or presenting norms. Imagine, for instance, that I am devising rules for organising conferences, such as how long talks should be, how speakers should be notified of their remaining time, how the audience should ask questions, etc. In order to do so, I will probably imagine a fictional conference and see how the rules that I am preparing would unfold in this fictional situation. I might abstract away some features of conferences if they do not matter for my purpose, making my representation unrealistic. Perhaps in my imagination the talks unfold with empty slides, for example. The fact that I am imagining a fictional situation in order to design (or later present) the rules of the conference does not mean that these rules are nothing but principles of generation that prescribe me to imagine fictional talks. They only play this role temporarily, for the sake of facilitating my reasoning or my exposition, but this temporary role is mostly psychological and inessential. The real function of the rules is to ensure that real, actual talks will work in an optimal way, and this is what these rules are truly about.

The same goes, I believe, for scientific models. The model of the Simple Pendulum is a set of norms for representing concrete pendulums. The simplest way of presenting these norms in full generality is to imagine a fictional pendulum. We need not attribute unnecessary features to it, such as a volume, if they do not matter, so long as we make clear that volume is not a representational part of the model (we make explicit the *character* of the model).[8] The fictional pendulum serves a psychological role in this situation, but the Simple Pendulum is not a work of fiction: its ultimate function is to be applied to concrete pendulums.

In sum, what fictionalism gets right is that abstract models *prescribe*. These prescriptions can be applied in imagination only, as is often the case when developing or presenting a model outside of a concrete context of use. However, these are not, in general, the main intended uses.

Knuuttila (2017) has proposed to view models as *kinds of concrete epistemic artefacts* (and so, their instances as epistemic artefacts). This view is compatible with our proposal: just like ordinary artefacts, scientific models have a function, and they are therefore associated with norms and values (they can be used appropriately or not, they can be good or not), which implies two levels of analysis.

An advantage of this conception is that it accounts not only for theoretical models, but also for computer simulations and material models, and so, it provides a unified ontology for epistemic representations at the communal level, despite the heterogeneity of concrete vehicles. A computer simulation has several instances. It is unlikely that what is licensed by scientists is a concrete program running on a particular computer rather than an abstract kind of program, identified by its functional structure. In all likelihood, copies of the program are ipso facto li-

8 This is not to say that idealisations cannot play a more positive role in inferences, for example, that of simplifying calculations or isolating relevant factors by construction (see for example Mäki 2009), but these aspects are beyond our present scope.

censed as representations of the same kind of thing as far as we have good reasons to think that the structure of the original is correctly reproduced in the copy. The same goes, I would say, for material models: we have seen that Phillips Hydraulic Computer has several instances, and I believe that any copy would be automatically licensed as a representation of the economy if we had good reasons to think that the causal structure of the original is correctly reproduced. So, what is licensed is always a *kind* of structure. What distinguishes material models, computer simulations and theoretical models in this view is mainly whether this kind of structure and associated demonstration rules are causal, computational or deductive.

Focusing now on target systems, we can see that, again, our two senses of representation bring about diverging intuitions. If interested in the contextual use of representations in particular contexts, we will consider that target systems are concrete entities, imaginary or real. But if we are focused on norms of representation in general, then it becomes more natural to think in terms of kinds of systems. In this respect, the fact that scientific models generally represent kinds rather than particulars is rarely emphasised in the literature, particularly when Gricean accounts are presented (Hughes (1997) mentions it, but simply assumes that a model can denote a kind without justification). This is quite surprising, given that models representing particular objects are the exception rather than the rule across most, if not all, theoretical disciplines. This fact comes out naturally from our theory, and at no ontological cost, since abstract models are *not* referential, but normative: they only acquire a referent in contextual use. As for targetless models, there is no difficulty in accounting for them either in so far as it is possible to devise indexical rules of interpretation that never apply to anything (but *would* apply if the context were appropriate: if we encountered a city configured like a chessboard for example). At the contextual level, this implies *imagining* applying these rules.

In sum, distinguishing two senses of representation, and assuming that one is primarily concerned with concrete entities and the other with abstract entities, helps resolve ontological issues satisfactorily. The way a model is normatively connected to various potential targets is an aspect of its communal status, which is better addressed at the abstract level, but the way it is actually handled and presented or used to make inferences about actual or imaginary targets is addressed at the concrete level of contextual use. With this division of labour, we do not need the complexities of accounts that attempt to capture all features of representation in a single theory. This demonstrates how distinguishing between two levels of analysis allows us to move beyond the debates on the representation relation, as well as on the ontology of representational vehicles and target systems.

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