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Epistemic Groundings of Abstraction and Their Cognitive Dimension

Sergio F. Martínez and Xiang Huang*+

ABSTRACT:
In the philosophy of science, abstraction has usually been analyzed in terms of the interface between our experience and the design of our concepts. The often implicit assumption here is that such interface has a definite identifiable and universalizable structure, determining the epistemic correctness of any abstraction. Our claim is that, on the contrary, the epistemic grounding of abstraction should not be reduced to the structural norms of such interface, but is also related to the constraints on the cognitive processes of specific abstractions. This suggests that we should understand abstraction as embodied in different kinds of abstraction practices.

+ Contact information:

Sergio F. Martínez, Instituto de Investigaciones Filosóficas, Universidad Nacional Autónoma de Mexico, Circ. Mario de la Cueva, C.U. Coyoacan, Mexico D.F. 04510, Mexico; e-mail: sfmar@filosoficas.unam.mx. Xiang Huang, School of Philosophy, Fudan University 220 Handan Road, Shanghai, 200433, P.R.China., email: hangxiang@fudan.edu.cn. Previously at Centro de Investigaciones y Estudios Avanzados del Instituto Politécnico Nacional, I.P.N., Mexico D.F.

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1. Introduction. Abstraction is related to the way we learn from experience and to the way we craft concepts in order to achieve goals. The epistemic problem of abstraction consists in finding a criterion to allow us to decide which abstractions are well grounded epistemically, and which are not. During the 20th century, the predominant tradition in the analytic philosophy of science sought to reduce the epistemic problem of abstraction to the study of the way in which the conceptual structure of science could be exhaustively analyzed as a logical structure. Well known accounts of abstraction usually emphasize the processes of adding or subtracting properties to representations that lend itself to such sort of analysis.[1] Martin Jones introduces a distinction between abstraction and idealization in the following way: "the term 'idealization' applies, first and foremost, to specific respects in which a given representation misrepresents, whereas the term 'abstraction' applies to mere omissions" (Jones 2005, 173). However, even if we concede the significance of the distinction between misrepresentation and mere omission in understanding how abstractions and idealizations operate in some important sorts of models and laws, there are important cases in which we learn from experience for which such distinction cannot be the whole story. For example, Sarah de Rijcke (2008) shows that Santiago Ramón y Cajal's abstraction of a

[1] The kind of philosophical analyses carried out by people like Michael Friedman and Bas C. van Fraassen, who have been able to show how mathematics allow us to account for many important aspects of abstraction in mathematically structured scientific theories, is an impressive achievement (Friedman 1983, van Fraassen 1980, Pincock 2007, Jones 2005). Nonetheless, we argue against the risk of thinking that the epistemic problem of abstraction can be treated solely by recourse to mathematical or logical analysis.

nerve cell was not simply a process of omitting certain features of it. Rather, it involved complex processes of scaffolded interaction between developing skills for drawing and employing other techniques for visualizing the nerves and the corresponding development of histological concepts. In such cases understanding the epistemic dimension of abstractions requires going beyond identification of what is omitted and what is misrepresented. Here, abstraction is a process that has to be understood in terms of the deployment and interaction of cognitive capacities and sorts of interaction with the world. In this paper we are putting forward two related theses. First, we motivate our conviction that the logicist tendency of reducing abstraction to the search for criteria that can guide the adding or subtracting of properties to representations in all domains of inquiry cannot exhaust the discussion about the epistemic dimension of abstraction. We argue that the epistemic role of abstraction cannot be reduced to analysis of concepts. There are different types of abstraction that presuppose different kinds of epistemic criterion. In sections 2 to 4, we introduce three contemporary theories of abstraction in order to show that, even though they can be thought as competitors, the best way to see them is as accounts of different kinds of abstraction not reducible to each other. In section 2, we introduce Hans Radder's and Nancy Cartwright's theories of abstraction. In Radder's theory, the extensibility of the concepts abstracted in practices of observation plays an important epistemic role, whereas Cartwright's theory proposes that the epistemic criterion should be established within a complex interaction that takes place between, on the one hand, assumptions of nature's capacities, and, on the other, practices of subtraction and concretization in the research project to identify the causal mechanisms involved in the phenomena under investigation. In section 4 we introduce Nersessian's account of abstraction in which the main epistemic weight comes from the power of analogical thinking. Our claim is not that these different accounts of abstraction (and many others) are just partial accounts that could be fit together like pieces of a jigsaw puzzle to give us a more general theory of abstraction. Instead, such accounts exemplify the different ways in which cognitive capacities (embodied in instruments, routines, heuristics, institutions, etc.) interact with our methods of learning from experience to generate grounded generalizations. This is not a smooth process – there are overlapping claims that often remain in tension with one another. However, the effect of those tensions goes beyond the scope of our thesis.

The second thesis we want to defend will be presented in the section 5. We argue that, understood as processes of *grounded generalization*, different kinds of abstraction practices can be identified by the different sorts of grounding. Such grounding can best be understood as constitutive of learning processes in which different cognitive capacities are deployed in different degrees. In this sense, the epistemic grounding of abstraction has a cognitive dimension which cannot be bracketed by appealing to traditional distinctions like that between discovery/justification, or by appealing to a sharp qualitative distinction between the psychological (and more generally cognitive) aspects of inquiry and the forms of explanations that matters in the philosophy of science. We suggest that generalizations supported by abstraction are, a) grounded in the different cognitive resources deployed in different research projects, and b), are sensitive to the particular goals directing these projects.

2. Radder and Cartwright on abstraction. Hans Radder starts by characterizing the classical doctrine of abstraction as ‘leaving out the irrelevant particularities or idiosyncrasies” and “mentally setting apart what is relevant and common” (Radder 2006, 110). This leads the inquirer from individual spatio-temporal instantiations to a general concept, which then can be taken to represent all the particular situations of a certain kind.

Radder argues that the classical doctrine of abstraction is wrong for the following two reasons: first, it is not plausible to presuppose that some sort of non-conceptual observation can be taken as the starting point of abstraction; and second, the grounding of an abstracted concept depends not only upon the appropriate actions of setting apart and leaving out, but also upon the concept’s extensibility.

In his book of 2006 Radder focuses in developing the notion of abstraction that is implied in the intended extension of concepts. An extensible concept points to some set of realizability conditions that (if concretely realized in actual space and time) could extend the concept to a specific new domain. Extensible concepts have a nonlocal meaning (transcending the meaning they have as interpretations of observational processes that have been realized so far). Thus, extensible concepts do not have a fixed extension.

For Radder the well-known Kantian idea that concepts structure the world is only part of the story. To the extent that concepts abstract from particular domains in the process of being extended to a new realization context the structuring meaning component of the concept shifts. Abstraction is the process through which we set apart the result of a particular type of process in order to use such result as scaffolding for further structuring[2]. Thus, such account does not lead to a separation between what is abstract in opposition to what is concrete, a rather usual view of abstraction, but it requires the recognition that human independent potentialities, extensible concepts with their nonlocal meanings, and local realizations of particular observational processes constitute "*sui generis* ontological categories that cannot be reduced to each other" (Radder 2006, 115).

Nor such account of abstraction is meant to be distinctive of scientific concepts or "abstract" science, it applies to ordinary as well as to rather esoteric scientific concepts. Abstraction as scaffolded potential realization in a new context is a rather fundamental and irreducible aspect of our cognitive life.

[2] In 1996 Radder suggests a more general account of abstraction (not limited to extensible concepts) than the one presented in 2006. To abstract is an activity that, "being rooted in a fundamental indeterminacy that is inherent in the results of experimental processes, reflects a sensitivity to as yet unrealized possibilities" (Radder 1996, 85). In this book Radder talks of different kinds of replication procedures and suggest a pluralism about abstraction that is compatible to the sort of pluralism we propose in this paper. The different kinds of abstraction would be associated to different types of "stabilizing procedures". But the elaboration of this point goes beyond our present concern.

We will end this brief account of Radder's account of abstraction pointing out the importance that a given notion of contingency plays in his characterization of the extensibility of concepts. Concepts are not extensible in any arbitrary direction. In advance of any attempted extension "it remains fully contingent whether or not, in actual practice, a concept can and will be successfully extended to a specific new domain". Radder makes clear that contingency here is used in its "common philosophical meaning of not being (logically or physically) necessary, rather that in its common sense meaning of being accidental or arbitrary" (Radder 2006, 103). It is this notion of contingency that supports the extensibility of the concepts and the implied notion of abstraction.

Nancy Cartwright (1989, 1999)'s theory of abstraction comes directly from the well-known move in the philosophy of science, which counters the empiricist emphasis on the law-like statements of regularities in science with the claim that these are not enough to offer a satisfactory theory of scientific explanation. Cartwright insists that regularities come into the picture only after presupposing ascription of tendencies (where the claim is about what things *do*) or of capacities (where the claim is about what things *cause*). It is the latter two that do all the work in non-*ad hoc* explanations. "For example, aspirins —because of being aspirins—can cure headaches. The troublesome phrase 'because of being aspirins' is put there to indicate that the claim is meant to express a fact about properties and not about individuals: the property of being an aspirin carries with it the capacity to cure headaches"

(Cartwright 1989, 141). Cartwright's notion of capacity and tendency come respectively from Aristotle and Mill. In order to understand the nature of the causal relations into which we are inquiring, we must isolate a particular causal relation from other related causal relations to determine its tendency and to measure its capacity. Scientists usually distinguish two kinds of causal truth. At the high level of generality, the ascription of capacities assumes that a causal relation between the cause *A* and the effect *X* occurs in every homogeneous background. At the low level, there are causal laws that articulate the causal relation between *A* and *X* in a population determined by experiments.

Corresponding to the two levels of causal truth there are two kinds of law-like statements about causation. The ascription of capacities corresponds to the notion of *abstract laws* "*A*'s do *X*", which expresses the general regular association between *A* and *X* without taking into consideration any particular concrete context of realization. They report what a particular cause *A* tends to do in ideal circumstances if it has been isolated from other causal factors, but these reports are not true or false in the sense that they do not literally describe the behavior of real material systems. This is due to the fact that in a real material system, a cause *A* can rarely be disentangled from other related factors. But, when concrete realization context *I* is specified in experiments, *causal laws* expressed as, "in *I*, *A*'s do *X*", offer causal explanations that tell us what *A* tends to do in a concrete experimental situation, controlling for all related factors. Nature's capacities are detected in terms of the causal laws, together with the presupposition about the stability and regularity of nature.

Placed in this context, abstraction is related to the process by which causal laws are obtained. Abstraction is not purely a construction of general statements resulting from leaving out, setting apart and testing in other experimental situations, but a constructive process that presupposes the notion of capacities. More concretely, according to Cartwright, abstraction is characterized by the following two kinds of processes: first, the process of *subtraction* to obtain the abstract law of the form "*A*'s do *X*", in which the causal relation between the cause *A* and the effect *X* is isolated from other related causal factors; and second, the process of *concretization* to obtain the causal law of the form "In *I*, *A*'s do *X*", in which the causal relation between *A* and *X* is manifested in a particular condition *I*, determined many times by concrete experiments. When abstract laws and causal laws use idealized concepts or idealized models, their abstraction is a process of *idealization*.[3] One example of these two processes of abstraction comes from Leszek Nowak (1980)'s interpretation of Karl Marx's law of value, which claims that the market prices of commodities correspond with their value of production. This an idealized abstract law subtracted from the reality of particular marketplace situations. In the subtraction, many factors that affect real market, such as the competition for producing and selling commodities, the difference between

[3] This is a simplistic way of characterizing Cartwright's notion of idealization. We use this way in order to avoid the complicate issue of differences between idealization and abstraction according to different authors (see Coniglione (2004) and Jones (2005) for reference).

the exports and the imports of a given economic system, the difference between the average agricultural capitals and the average remaining capitals in a given economic system, the merchant profit, etc., are bracketed off. Once the abstract law of value is subtracted, what we have is an idealized relation between a commodity's value of production and its prices. However, although this abstract law is supposed to indicate a causal tendency in an idealized situation, it does not and is not meant to describe what happens in real economical practices. In order to describe the real economical practices, Marx searched for local causal laws by concretization, or by adding back the factors omitted by the above presuppositions. It is by analyzing the local causal laws that Marx was able to criticize the capitalist economy and society (Nowak 1980; Cartwright 1989, 203-205).

3. Radder's criticism of Cartwright's approach. Radder argues that Cartwright's theory of abstraction is not sustainable for the following two reasons:

A1) Cartwright's Aristotelian account of abstraction, "conceived as a method of acquiring concepts or forming theories, is untenable because of the fact that concepts and theories structure (our experience of) the world" (2006, 141);

A2) Cartwright's concretization is not sustainable because, firstly, it is trivial due to the fact that it is the inverse process of leaving out; and, secondly, Cartwright here does not take in consideration that the extensibility of concepts is what makes them abstract.

We believe that both reasons are questionable. Let's look at A1) first. A1) takes Cartwright's use of the Aristotelian notion of abstraction as evidence for her being a defender of the classical doctrine of abstraction, according to which abstraction begins from some "direct or non-conceptual observation of a number of particular situations". As we have seen, Radder argues that the classical doctrine is untenable because observation is always conceptually interpreted.

However, even though Cartwright takes her inspiration from Aristotle, it is not correct to say that she takes for granted non-conceptual observation as the starting point of abstraction. Cartwright's aim is not the defense of the classical doctrine but, instead, the rejection of the idea that Humean regularity statements are sufficient for scientific explanation. The abstraction of causal law based on subtraction and concretization needn't presuppose a non-conceptual observation. In fact, it can easily be made compatible with Radder's Kantian position vis-à-vis scientific observation. As Cartwright says: "[e]ven what are supposed to be the 'purest' empirical assertions, like 'this facing surface is red', employ concepts which cannot be given ostensively but only make sense relative to an entire structure of other concepts in which they are embedded" (1989, 180). The difference between Cartwright and Radder does not concern the Kantian notion of observation, but rather concerns their commitments to different sorts of epistemic criterion.

As we have seen, Radder embraces a consequentialist methodology according to which, if the process of generalization is inevitably interpreted by concepts, its epistemic criterion and empirical contents should come from the extensibility in other type of domains. For Cartwright, as also for Mill, nature's capacities or causal tendencies are presupposed in subtraction and concretization, and thus, once detected and manipulated in experiments they can be relied upon as an epistemic resource to justify the result of abstraction. The ideal model of the epistemic criterion for abstraction adopted by Cartwright is Mill's "mixed method of induction and ratiocination". It is the process of "'going upwards' from experience to general principle and 'argu[ing] downwards from that general principle to a variety of specific conclusions'" (Cartwright 1989, 183). That is, subtraction aims to set apart a general statement about the capacity, or the tendency, of a particular causal factor, and to leave out any other potentially disturbing causal factors as specified in terms of *ceteris paribus* conditions. Cartwright's (and Mill's) going-upwards-step doesn't suffice by itself to obtain abstract laws with explanatory and predictive power, and thus must be paired with concretization to generate relevant explanations and predictions. That is Cartwright's version of Millian ratiocination: some disturbing causal factors, isolated in the inductive process, are then added back to the concrete material situation in which the capacity of the considered causal factor manifests itself.

Still, Radder is not alone in finding Cartwright and Mill's two step abstraction suspiciously pre-Kantian. Humphreys, too, has expressed doubts about whether there is a plausible epistemic account for how abstract laws are subtracted from particulars that can avoid recourse to Aristotelian non-conceptual observation (Humphreys 1995, 158-59). Let's suppose that subtraction or Millian induction is a process of Aristotelian abstraction as leaving out, in which, "we begin with a concrete particular complete with all its properties" or "[w]e then strip away—in our imagination—all that is irrelevant to the concerns of the moment to focus on some single property or set of properties" (Cartwright 1989, 197). The question for Mill and Cartwright seems to turn on the 'irrelevant' – for if we do not assume non-conceptual observation as our criterion here, how can we justify our subtraction on epistemic grounds? For Radder, and perhaps for Humphreys, a consequentialist explanation relying on the extensibility of abstracted concepts is more plausible: in this way, we do not have to assign any particular epistemic weight to the process of subtraction. For Cartwright, however, it is not the metaphysically "essential properties" but rather some stable causal mechanism that subtraction aims to grasp. Similar to Mill's insistence that scientists' cognitive competency can offer sufficient justification for abstraction practices, Cartwright suggests that ontological presuppositions about the presence of nature's capacities, together with experimental manipulation aiming to establish the reliability of such presuppositions, can serve as the epistemic ground of subtraction. Capacities of nature, material and social conditions should be considered as the satisfactory epistemic resources necessary to support the claim that a causal relation exists, even if such statements are not infallible.

Radder's A2 has two parts:

(A2.1) Concretization (as understood by Cartwright) does not takes in consideration the extensibility of concepts; and

(A2.2) Concretization (as understood by Cartwright) is trivial as it is taken as an inverse process of subtraction.

According to Cartwright, concretization is the process through which we obtain those concrete causal laws that measure capacities through experiments in a context in which certain interacting factors previously isolated by the *ceteris paribus* conditions are put back in. In fact, *Cartwright's notion of capacity is characterized by a kind of extensibility in as much as the structures that represent a capacity should be persistent in different environments*. For example, Cartwright says: "To infer the stronger claim—what I call a capacity claim—one must suppose that the causal possibilities that are established in that situation continue to obtain in various different kinds of situation" (1989, 147). In other places she associates this persistency of capacities to the “the exportability of information”: “we gather information in one set of circumstances but expect to use it in circumstances that are quite different” (1989, 227). Like Radder, Cartwright assigns an epistemic weight to the exportability of information, even though she doesn’t take it as the only epistemic resource for grounding abstraction. With respect to the case of concretization, a kind of extensibility is required to explain the relationship between two interacting causal laws in different domains:

> The first law gives evidence for a capacity, and that the capacity will exhibit itself in a new causal law in any new test situation. That assumes that capacity remains intact. It is, of course, part of the point of taking capacities seriously as things in the world…that they should remain intact from one kind of situation to another. But that does not mean that there can be no exceptions; it means that any exception requires a reason. Probably the most common reason for a capacity to fail to obtain in the new situation is causal interaction (1989, 163).

Here, contrary to what Radder says, Cartwright doesn’t ignore extensibility. She is characterizing *a different kind of extensibility*. Whereas Radder takes the extensibility as the applicability of an abstract concept in a novel material realization domain, for Cartwright, extensibility is a sign of a stable causal relation allowing for prediction and manipulation. What this observation suggests is that *Cartwright and Radder are modeling different kinds of* *abstraction practices, which are grounded in different notions of extensibility*. If Radder conceded the possibility of other kinds of abstraction that are not based on the observation practices that he has characterized, then he would be forced to grapple with Cartwright's causal interpretation of extensibility. As we shall see, our understanding of Radder and Cartwright's different versions of extensibility receives additional support from the discussion about the triviality of concretization.

In concretization, or the process that leads from the top back down, various of the factors taken away in subtraction are added back in, as we have seen in Nowak's example of Marx's law of value. However, it is important to point out that *the conditions of subtraction are not the same as the conditions of concretization*.[4] As Cartwright says:

> To get back to the concrete laws that constitute its phenomenal content, the omitted factors must be added in again. But where do these omitted factors come from? I have already described the answer I believe in: given a theory, the factors come from a list. But the list provided by any given theory, or even by all of our theories put together, will never go far enough. There will always be further factors to consider which

[4] Radder correctly points out that in cases of the replication of an observation through a radically different observational process, there are no omitted factors at all (2006, 101-102). Thus, we agree with Radder that there are types of abstraction that do not need concretization in the sense of Cartwright; hence, Cartwright's model of abstraction should not be taken as describing all abstraction practices. However, what we aim to show in this paper is that 1) not all concretization is an inverse process of subtraction, and 2) concretization can be seen as a kind of extensibility.

> are peculiar to the individual case. I call this the 'problem of material abstraction'. (1989, 206-7)

For Cartwright, *material conditions are not mere contingent backgrounding circumstances that the theoretical treatment of abstraction dispenses with*. On the contrary, when realized in a concrete experimental practice, they, together with the theoretical components deriving from the research problematic, specify the context in which one concretization is possible. For example, the abstract law of the operation of bubble chamber is this: "a passing charged particle has the capacity to cause bubbling in a liquid in a superheated state" (1989, 209). However, before doing experiments, Donald Glaser did not have any reason to think that the superheated media for his chamber could not be xenon, but could be diethyl ether. This difference is decided by material conditions of actual experiments in concretization, but it need not appear in the list that represents the process of subtraction.

4. Nerssesian's approach. The forms of concretization are thus inherently very variable. In fact, many times concretization is not only not an inverse process of subtraction but also a creative strategy of theory construction. This can be seen in the example of James Clerk Maxwell's construction of the electromagnetic field studied by Nancy Nersessian (2002, 2008). Nersessian and Cartwright share the same ultimate concern: how generalization functions in and is derived from empirical knowledge. The difference is that, whereas in

Cartwright's theory, abstraction aims to give the researcher a causal account of phenomena, in Nersessian's modeling theory, the aim of abstraction is to obtain generic models that allow for a unified explanation of phenomena.

According to Nersessian, the generic model abstraction "is the process of constructing a model that represents features common to a class of phenomena" (2002, 129). She uses the process by which Maxwell developed his mathematical theory of electromagnetic field in these terms: "… once Maxwell formulated a satisfactory model representing a specific mechanism, he considered those abstract relational structures of the mechanical model that could account for the electromagnetic phenomena, formulated the equations of the abstract model, and substituted in the electromagnetic variables" (Nersessian 2008, 28). We can thus distinguish three steps in Maxwell's theoretical development. The first step can be characterized this way:

S1) In certain specific circumstances, experiments are performed whose results fall under the scope of a local model expressed by law-like regularity claims, very crudely of the form "In I, A's do X" ("I" being specified by the *ceteris paribus* conditions of the experiments).

In our case, Nersessian foregrounds the visual version of the vortex-fluid model that Maxwell constructed to account for the results of Michael Faraday's experiments concerning electromagnetic force. Roughly the model can be expressed as "In an electromagnetic field specified by Faraday's experimental conditions (I), repulsive and attraction force manifested by magnetic lines (A) can be modeled as vortex actions (X)". In a series of experiments performed from 1825 to 1831, Faraday observed the formation of regular magnet lines in iron filings and interpreted this phenomenon to imply that electromagnetic space is a force field of currents and charges. Maxwell accepted this idea and suggested that the forces were transmitted through Newtonian aether. In a paper published in 1855-6, Maxwell "provided a kinematical analysis of magnetic lines of force as representing the intensity and direction of the force at a point in space on analogy with the flow of an imaginary, incompressible fluid through a fine tube of variable section" (Nersessian 2002, 131). In a paper published in 1861-2, Maxwell specified this imaginary fluid with the form "of centrifugal force of vortices in the medium, with axes parallel to the lines of force" (2002, 132). This vortex model should be established under a series of *ceteris paribus* conditions (I) such as: "(1) electric and magnetic forces are at right angles to each other, (2) magnetism is dipolar, and (3) the plane of polarized light passed through a diamagnetic substance is rotated by magnetic action" (2002, 132).[5]

The visual model of the vortex is a "physical analogy" in which it is assumed that the attractive and repulsive forces operate as stresses in a mechanical aether. Given this hypothesis, one can assume that "relationships that hold in the domain of continuum mechanics will hold in the domain of

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[5] In Nersessian (2008), *I* is characterized by a series of "constraints drawn from the target domain of electricity and magnetism, the source domains of continuum mechanics and machine mechanics, and from the constructed models themselves" (55).

electromagnetism" (2002, 136). We can interpret his analogical generic modeling as a process of going through steps of subtraction to obtain a general law-like statement, "A's do X" from particulars.

The process to obtain the general laws from these models is the second step:

S2) The statement without the restriction to the circumstances "A's do X" is subtracted.

In S2, "the mathematical representation of various magnetic phenomena is derived by Maxwell from the vortex-fluid model". Maxwell in this step "had not yet specified a causal process in the aether connecting electricity and magnetism, and so claimed not to have provided a mechanical explanation for their interaction" (Nersessian 2002, 136). Maxwell's aim is to obtain a generic and idealized calculation system which didn't necessarily have to be a representation of real physical system. Like Cartwright's similar use of subtraction, in this step the abstract laws articulated mathematically are obtained. However, in distinction from Cartwright's use of subtraction, this is not synonymous with the process of isolating a determinate causal relation from all the other related causations manifest in singular causal situations.

In the third step, Nerssesian takes Maxwell to be undertaking a process analogous to Cartwright's concretization:

S3) The application of this statement "A's do X" in explanation and prediction is the method of concretization.

The purpose of concretization for Maxwell is to enable him to explain the vortex motion in a physical system with (causally) extensible elements. [6] There is a problem of making the model real: if the attractive and repulsive forces in electromagnetic field are stresses in a mechanical aether, then there will be friction at the places of contact among vortices, which will lead to jamming. The problem is solved by Maxwell with an interesting strategy: "by supposing that a layer of particles, acting as idle wheels is interposed between each vortex and the next, he stipulated that the particles would revolve in place without slipping or touching in direction opposite to the vortices" (2002, 149). The invention of the notion of idle wheels seems *ad hoc* for eliminating the consideration of friction between adjacent vortices. However, the invention of the idle wheels "is consistent with the constraint that the lines of force around a magnetic source can exist for an indefinite period of time, so there can be no loss of energy in the model" (2002, 149). Maxwell thought that, with the help of the idle wheels, the mathematical laws constructed in S2 can safely offer an explanation in the real physical system grounded in the extensibility of some elements in the model.

[6] Extensibility in this case can be identified with the sense of causal extensibility grounded on capacities we found in Cartwright's account of abstraction, with a caveat. The interesting point (made to us clear by a referee) is that even though Maxwell is clear that the system he is instantiating need not exist in nature the kinds of causal relations between vortices and idle wheels support the extensibility of the physical system in question. In other words, the extensibility in question is not aggregative. The extensibility of parts of the system does not add up to the extensibility of the system as a whole. This sort of non-aggregative extensibility seems to be behind grounded generalizations supported by analogical reasoning.

The direct lesson we learn from Nersessian's case study is this: it is quite clear that in this case concretization is not inverse to the process of subtraction. The construction of the analogy of idle wheels comes about through concretization, which is organized to give a causal explanation of the friction among moving vortices. They have not been considered in the earlier steps S1 and S2, because the friction among the vortices is a question appeared only after the abstract model of vortex had been invented through S1 and S2. The question is dependent on the invention and manipulation of an abstract model in a particular problem-solving situation.This lead us to a reconsideration of A2.2. Radder and Humpreys are correct in arguing that concretization should not be understood as an inverse process of substraction. However, concretization need not be understood in this way, as the cases of Glaser and Maxwell show.

We hope that our line of argument by now makes it clear why Radder's criticism of Cartwright, even though it makes an important point, overlooks a crucial feature of the problem under discussion, for contrary to Radder's premise, extensibility turns out to be a different sort of relation under certain different circumstances. In fact, in Radder's, Cartwright's and Nerssesian's theory, abstraction's extensibility is embodied in different practices. The sort of extensibility on which Radder focuses is basically a kind of aggregative extensibility, in which the epistemic role of extensibility resides in its capacity of applying in other domains. This notion of extensibility assumes that a causal law can be characterized by the aggregation of the extensions of the law in the different concrete experimental situations in which it is operative. Whereas in the sort of practices of abstraction that Cartwright and Nersessian focuses on, the aim is to obtain a causal explanation that often cannot be reduced to the sum of its extensions in concrete experimental situations. In Cartwright's and Nersessian's sense of abstraction, the epistemic resources configuring a process of abstraction include not only the aggregative extensibility of a causal law, but also domain-specific ontological considerations (that often lead to non-aggregative extensibility). On Nersessian's account, abstraction is closely related with mental modeling and analogical inferences. Correct analogical inferences characterize the appropriate extensions. As in Cartwright's account, the epistemic relevance of these types of extensibility cannot be satisfactorily articulated merely in terms of logical structures and methodological rules. Whether extensibility is aggregative or not is a question that has to be answered depending on the situation at hand, and that requires that a model is designed with the right sort of extensible elements.

Thus, it seems more appropriate not to talk of one relation of extensibility but rather of different types of extensibility associated with different presuppositions about how our interaction with the world has a role in constructing and grounding what is ontologically the case. In the case of Radder, our interactions with the world only reveal what is contingently there (that for Radder means that our interactions reveal something that is not logically necessary). But what our interactions with the world reveal to us can be contingent in a different sense; in the case of Cartwright our interactions with the world determine (fallibly) the causal-material contexts in which objective causal relations can be identified; and, in the case of Nersessian, our interactions with the world, in order to preserve their relevance in relation to our inquiry, have to be mediated by epistemically relevant models. The relevance in question passes through the identification of the right sort of analogy. In other words, in the above three types of extensibility, different ways of interaction with the world configure the different kinds of epistemic criterion for abstraction (grounded in different types of contingently stable interactions with the world). Our argument points to the fact that each of the three types of abstraction we have examined individually can tell us only a partial story of the epistemic dimension of abstraction; and, in particular, the whole story about abstraction can't be extracted from a theory that identifies it with a shared logical structure.

Our reflection on Radder, Cartwright and Nersessian's studies of abstraction strongly suggests that, if the epistemic import of abstraction is dependent on its grounding, then the shared logical structure among them simply will not account for all epistemically relevant instances of abstraction. That means that we have to pay attention to the way in which interactions with the world give way to contingently stable extensions; such extensibility is what makes them abstract (Radder's insight).

5. On the cognitive dimension of abstraction. Our rejection of past and current attempts to account for the epistemic relevance of all abstraction processes in terms of a shared logical structure in favor of one that adopts a pluralist attitude toward different ways to model abstraction practices receives support from recent cognitive science research on abstraction that suggests that different processes of abstraction are associated with different practices. In our view, an epistemically and methodologically sound theory of abstraction cannot be provided by a model that does not take into account of the embeddedness of abstraction in cognition's workflow. Different kinds of abstraction are associated with different cognitive resources, and the determination of what kind is relevant is given to us by the contextual factors that configure different kinds of epistemic norms. In this section, we shall see some examples of these studies. It is important to keep in mind that our aim is not to show how the different accounts of abstraction in the philosophy of science can be modeled by one specific cognitive model of abstraction. Rather, our point is the following: looking at the variety of models and approaches to abstraction in the cognitive sciences, it is evident that abstraction fills different epistemic roles, shaped by different cognitive purposes.[7] Thus, we get support for the thesis that a plurality of abstraction practices is epistemologically relevant in the philosophy of science.

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[7] Of course, our thesis relies on the assumption that abstraction as a psychological process is embodied or grounded, as such claim is defended by psychologists like the ones we discuss below. In particular see Bickhard (2001, 2009), Barsalou (2008), Anderson (2003) for arguments supporting (from different perspective) such point of departure.

It might be objected that the sort of abstraction processes involved in doing science, and the sort of abstraction processes in children and common folk addressed in the psychological literature are quite different, and thus that the conclusion we want to draw is unwarranted. That is, we cannot extrapolate from findings about the plurality of kinds of abstraction in psychology to the plurality of kinds of abstraction in the philosophy of science. This objection assumes a fundamental disjunction between the cognitive processes underlying ordinary life and those underlying the sciences that we think is untenable[8].

Quite often psychologists have tried to understand the general features of abstraction, such as generalization, creativity, problem solving capacity, etc, by classifying different kinds of abstraction according to their cognitive purposes, precisely for the reason that different cognitive purposes implies different methodological (and sometimes epistemic) norms for abstraction. This idea can be found in Jean Piaget's study on the development of abstract thought among children as they age. Piaget distinguishes between empirical abstraction that is used to organize observed objects and reflective abstraction, which is abstraction about concepts and actions (Piaget, 1968). The cognitive structures of these two processes are different: in the first, the basic operation is that of setting up correspondences between words and their signifieds,

[8] Carruthers (2002) and Eraña and Martínez (2004) provide specific arguments for the continuity thesis independently of claims about abstraction. Radder, Cartwright and Nersessian support versions of the continuity thesis as part of their accounts of the sort of abstraction that matters in science. Extensibility for these authors is a general feature of human practice.

whereas in the second, the coordination of actions serves as the basis for the higher order cognitive acts (for instance, taking empirical abstractions as an object of further abstraction) .

Colunga and Smith (2003) offer a more sophisticated explanation of this differences based on the results of strictly controlled experiments. According to Colunga and Smith, after a brief period in which children learn instance-by-instance label-words, children begin to generalize the regular pattern or structure of the objects observed through associative learning of similarity. The generalized regularity is abstract in the sense that it is a rule-like guide helping the children to apply it to instances never seen before. This process is sensitive to different contexts, because the patterns of regularities are characterized not only in terms of properties shared by the objects, but also by a special way to classify or to partition objects. The abstract category of solid things, for example, is related to the shape of things, whereas the notion of non-solid thing is related to the material of which things are composed. Therefore, children "become learners who have partitioned the learning space into fundamentally different kinds of problems—learning about words, learning about animal sounds, learning about objects, learning about substances" (p. 1213). For Colunga and Smith, the effect of these partitions is to sensitize our manipulations of mental concepts to various contexts associated with different cognitive purposes. The relations between contexts and purposes not only provides a grounding for abstraction, but it leads us to a pluralist view of abstraction in order to understand how different sorts of learning processes are related to different sorts of partition, which entail, in turn, different sorts of abstraction.

In cognitive linguistics there are several proposals exploring the idea that abstract concepts are understood through metaphors. For Lakoff and Johnson (1999, ch.5) metaphors like "time flies" should be seen as mappings of a physical experience of spatial movement that gives us a figurative understanding of time. Alternatively, Lera Boroditsky (2000) claims that people's thinking about "the abstract domain of time" is built on representations of more experience-based domains, but not on the physical experience itself. This suggests that abstraction may occur differently at different cognitive levels, and one has to understand those levels. If abstract thinking about time should be understood in relation to spatial thinking (and not necessarily in relation to the experience of motion itself) then our idea of causality may well change depending on the way we think of the relation between time and space. Following this train of thought, it seems natural to think that different views of abstraction depend on the different cognitive purposes we might have in a given situation. In the work of Lakoff, Johnson and Boroditsky, monism about abstraction clearly leads us to the wrong conclusions.

From a different perspective, Lawrence Barsalou takes a similar stance about the plurality of processes of abstraction. According to Barsalou abstraction is a cognitive mechanism in which "association areas in the brain capture modality-specific states during perception and action, and then reinstate them later to represent knowledge”. For example, “during visual processing of a car, populations of neurons fire for edges, vertices and planar surfaces, whereas others fire for orientation, color and movement. The total pattern of activation over this hierarchically organized distributed system represents the entity in vision” (2003, 1179). Two stages are involved in this mechanism: one in which the modality-specific patterns are activated through perception and action and stored in memory; and then the re-enactment stage, in which associated neurons “later reinstate the pattern in the absence of bottom-up stimulation”(2003, 1180). The application of the re-enactment stage can be taken as a simulation of what the original modality-specific stage delivers, that is, simulators “integrate information across a category’s instances”, and simulations “are specific conceptualizations of the category” (2009, 1282). The concrete abstraction realized by a particular simulator, however, only partially determines the content of an abstracted concept, as a concept can be re-enacted by different simulators in response to different contexts. As Barsalou says, “on one occasion, the car simulator might produced a simulation of traveling in a car, whereas on others it might produce simulations of repairing a car, seeing a car park and so forth” (2003, 1180). Corresponding to distinct action-situations such as driving, washing or repairing, different simulators endow the concept of car with different properties structured by different types of relations. A simulation realized by a determinate simulator in this sense is holistic and contextual in character.

The fact that many simulations determine an abstracted concept makes an abstraction dynamic in the sense that “although a relatively fixed set of property and relation simulators may exist for a person at a give point in time, the particular ones used across occasions vary considerably” (2003, 1183). What triggers a simulator and not others is determined by such exiguous factors as frequency and recentness: “some simulators may be more likely to be applied than others. Simulators applied frequently in the past will have an advantage, as will simulators applied recently” (2003, 1183). The point that we want to emphasize is that extensibility of a simulation depends on the simulator. Thus, Barsalou can be taken as suggesting a way in which the different types of extensibility can be cognitively grounded.

The dynamic character of abstraction implies that searching for a unique theory of abstraction is pointless, since abstraction processes must function differently relative to cognitive purposes. As Barsalou claims, “no one abstraction can be identified and motivated as *the* summary representation of a category, because an infinite number are possible” (2003, 1183). Epistemic norms are thus often needed to determine which simulation should be triggered. And the role of norms will depend on the type of abstraction that a situation or context demands.

Barsalou proposes a list of six types of abstraction investigated by cognitive scientists, as follows:

1) Categorical knowledge - the process of relating appropriately a concept with the term of it, e.g., the concept of chair with the term “chair” and not with “table” or “cat”.

2) The behavioural ability to generalize across category members, which is an abstraction of the knowledge about the behavioural properties of a category, e.g. “dogs bark”.

3) Summary representation - generalization of things such as a declarative rule, a statistical prototype or a connective relation.

4) Schematic representation - abstraction of the critical relevant properties of a category’s exemplars, discarding any irrelevant feature. Schema may be distorted to idealize or caricature a category.

5) Flexible representation – the application of summary representation to many different tasks, including categorization, inference, language comprehension, reasoning, etc.

6) Abstract concepts, which is the abstraction of the abstract concepts such as “pleasure”, “courage”, etc (2003, 1185; 2005, 424-25).

Radder, Cartwright and Nersessian point to different ways in which different processes of abstraction can enter into scientific concepts and practices. For example, Radder’s theory of abstraction could be explained against the background of Barsalou’s approach in the following way: practices of finding the regular pattern in a set of observed objects and extending this pattern to other areas of observation are realized through modality-specific mechanisms associated with categorical knowledge, summary representation, or schematic representation. In these cognitive processes, specific simulators are established in order to let the subject observe the objects in a determinate way. Besides, the re-enactment process specifies extensibility of an abstracted concept, which should be understood as a kind of flexible representation, in which “summary representations can be applied flexibly to many different tasks” (2003, 1185). It is a step related to the subject’s background knowledge and skill more than to her capacity of capturing the correct description of a concept.

Quite differently, Cartwright insight that causal relations are based on nature’s capacities is supported by the extensibility of behaviors, the tendency of such behaviors to generalize across category members. Causal explanations such as “aspirins relieve headaches” or “electromagnetic forces cause motions perpendicular to the line of action” refer to nature’s capacities via the behavioral tendencies of aspirins’ and electromagnetic forces’. In Barsalou terminology, such causal relations are abstract products of simulators for aspirin and of electromagnetic force, developed through modality-specific mechanisms that will allow us to interpret a particular headache and a particular motion perpendicular to the line of action as result of such causes. As we have seen, Cartwright distinguishes between the abstract law articulated as “A’s do X” and the causal law articulated as “In I, A’s do X”. The first is a general law about regularity subtracted from experimental data, whereas the second is the local causal law about a capacity of nature obtained by concretization. From Barsalou’s perspective, the abstract law can be characterized by summary and schematic representations, in which a regular pattern is generalized from experimental data. Whereas the local causal laws are results of flexible representation, in which a concrete application domain *I* is detected by skillful scientists in experiments.

In Nersessian's generalization by analogy, besides summary representation, schematic representation and abstract concepts involved in the construction of a model, flexible representation plays the special role of transferring some regularity from one kind of phenomena to another kind of phenomena through analogy. Nersessian is calling attention to the importance to generalizations formulated in terms of generic abstraction that cannot be characterized merely as an application of some regular rules in new domains, but has to be characterized as a creative process involving the manipulation and modification of the original regular patterns in such a way that a new "natural kind" emerges as part of the objective phenomena science deals with. In Barsalou's words, "when the same configuration of property and relation simulators can be applied to different categories, analogy becomes possible" (2005, 422). The generalization by analogy might be explained as the core of what Barsalou calls flexible representation. Flexible representations are not merely a re-enactment simulation of those modality-specific patterns triggered by the original contextual simulators, as in the case of prediction. In an analogical representation the re-enactment simulation is not the inference of a conceptualization in a similar situation to the one in which this conceptualization is initially activated, but is a creative inference involving the identification of a different kind of phenomena, a more abstract kind. In Maxwell's case, patterns and regularities originally found in phenomena involving fluids and electrostatics were transferred into a new kind of phenomena (electromagnetic ones). According to Barsalou, the successful establishment of this creative step depends on whether the newly transferred conceptualized pattern can allows us to re-enact simulation applicable in the area of electromagnetic phenomena. Maxwell's invention of the idle wheels might be considered as an attempt to construct suitable simulators in environments mediated by aether, in order to make possible the re-enactment of the vortex-fluid model in future prediction and explanation.

Understanding how different cognitive resources play a role in explaining different sorts of epistemic grounding of abstraction promoted by different philosophers requires more careful and systematic investigation. But this is outside of the scope of this paper. Also, it is important to say explicitly that our thesis is not committed to the specific way in which Barsalou models the plurality of abstraction processes in terms of modality specific mechanisms. We consider it a plausible explanation of the way in which the plurality of abstraction processes relevant in scientific and everyday reasoning is grounded in cognitive resources.

However, we think that *understanding the epistemic grounding of abstraction* requires going beyond an account like that of Barsalou, it requires introducing concepts like that of affordance[9]. Affordances can be seen as (expression of) patterns

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[9] The concept of affordance was introduced by Gibson (1979) as the key concept of his ecological approach to perception. Gibson's affordances allow us to say that meaning is not "inside" the perceiver, but rather that meaning is constitutive of affordances that are part of the environment. Affordances can be understood as abstract features of the environment pointing to possibilities of action. Affordances are then intrinsically relational (see Chemero 2009, Ch. 7). In this view affordances would then be an embodiment of behavioral abstractions, schematic and summary

of potential action (see for example Borghi 2000). For Borghi, affordances constitute genealogies of ways of knowing how to do things that in the case of science are usually articulated by scientific practices and theoretical concepts like that of "electromagnetic field". Different types of abstraction can be seen as different ways of organizing the different sort of norms and cognitive resources that form the entrenched patterns of activity that coalesce into a practice. From this perspective, affordances capture abstract thinking as embodiments of ways of knowing how that can be extrapolated into new domains of knowledge (assuming that such affordances embody the right epistemic norms). Barsalou's account is centred on the integration of modality. Its specific processes might seem quite different from an account of abstraction based on affordances, but *they coincide in promoting a view of abstraction according to which the relative weight and the genealogy of different processes of abstraction scaffolds its epistemic function.* To the extent that those empirical investigations support this basic point, they are supporting our thesis.

Summing up, cognitive studies of abstraction give us good reason to adopt the pluralist stance according to which different (epistemically relevant) types of abstraction will always arise from different cognitive resources and epistemic norms, and must be understood relative to such differences. Such pluralist approaches allow us better to understand the way in which the interplay of different types of abstraction

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representations at once. However, different affordances would embody different abstraction processes. For example, Cartwright's capacities embody affordances implicit in an experimental set-up, Nersessian's generic modeling points to abstraction processes embody in affordances that can be understood as flexible representations connecting different kinds of things.

processes plays a role in the generation of stable practices embodying a complex variety of implicit and explicit epistemic norms.

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