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Distinguishing Between Inter-domain and Intra-domain Emergence

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Abstract
Currently, there are almost as many conceptions of emergence as authors who address the issue. Most literature on the matter focuses either on discussing, evaluating and comparing particular contributions or accounts of emergence, or on assessing a particular case study. Our aim in this paper is rather different. We here set out to introduce a distinction that has not been sufficiently taken into account in previous discussions on this topic: the distinction between *inter*-domain emergence—a relation between items belonging to different ontic domains—and *intra*-domain emergence—a relation between items belonging to a same ontic domain. Our final purpose is not to assume and defend a definite stance on emergence, but to stress the relevance of such distinction when attempting to argue for or against emergence, in the first place. We will also address the connections between emergence so distinguished and more general philosophical perspectives, suggesting where would reductionists and pluralists stand with respect to intra- and inter-domain emergence.

Keywords Inter-domain emergence · Reductionism · Pluralism

1 Introduction

The idea of emergence appeared clearly in the philosophical thought in the late-nineteenth and early-twentieth centuries along with British emergentism (see McLaughlin 1992). However, the rest of twentieth century's philosophy of science, under the strong influence of positivism, was marked by reductionism. It was only during the last decades that the notion of emergence has "reemerged" not only in philosophy, but also in the scientific field (Cunningham 2001). The reasons for this revival are varied. One of them is the high development of the interdisciplinary field of the sciences of complexity. Another reason can be found in the studies about mind and consciousness. Of course, the boom in the computational resources to model non-linear dynamical systems has also exerted a great influence on the appeal to the notion of emergence in different scientific disciplines. But, in the field

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of philosophy, the return of emergentism was possible thanks to the collapse of positivism, along with its search for the reductive unification of sciences.

At present, after many years of discussion, there are almost as many conceptions of emergence as authors who address the issue. Here we will not attempt to discuss all that has been said about emergence, a task that would be impossible to accomplish in a single article anyway. This is not a case study either: in the literature about emergence, there are many interesting articles devoted to studying particular cases, but this is not one of them. Our aim is only to introduce a distinction that has not been sufficiently taken into account in the discussions on this topic: the distinction between inter-domain emergence—a relation between items belonging to different ontic domains—and intra-domain emergence—a relation between items belonging to a same ontic domain. The final purpose is not to assume a definite stance on the matter, but to stress the relevance of the distinction when attempting to argue for or against emergence from different philosophical perspectives.

With this aim in view, the article is organized as follows. In Sect. 2, we will begin by introducing some terminological precisions in order to avoid confusions in the subsequent argumentation. Section 3 will be devoted to analyze the relationship between emergence and reduction, in the light of recent claims about the compatibility between them. Although we will not attempt to offer a precise definition of 'emergence', in Sect. 4 we will consider the features shared by almost every characterization of the notion. This paves the way to introduce, in Sect. 5, the distinction between inter-domain and intra-domain emergence. On this basis, in Sects. 6 and 7 we will consider how these two forms of emergence would be respectively assessed from different philosophical perspectives. In Sect. 8 we will show that there are situations usually conceived as cases of emergence, but that do not fall comfortably under any of the two forms of emergence as previously characterized. We will argue that these are cases of inter-domain emergence, but of such nature that need to be distinguished from the traditional cases because they involve a kind of second-order multiple realizability. We recapitulate the different forms of emergence examined in the Conclusions.

2 Some Preliminaries

Since 'emergence' is a highly polysemantic word, it is convenient to begin by introducing certain terminological precisions that will let us to clarify what the present article deals with, avoiding some rather common confusions.

The first distinction relevant to our purpose is that between *diachronic* and *synchronic* emergence (Kim 1999; Rueger 2000; Humphreys 2008). Drawing this and other distinctions in this paper require that we turn to the notion of *domain*. We here consider that, in principle, each theory refers to a particular domain. Of course, it can be the case that two theories refer to one and the same domain, and it can be the case that a theory (or law) connects items belonging to different domains. We follow Lindley Darden and Nancy Maull's (1977) notion of domain. For them, domains consist of items taken to be facts or objects related to the problem(s) a theory aims at addressing, this is, on which a theory is intended to have application. Note that this is an ontological, not an epistemic notion of domain.

Diachronic emergence, then, is a time process through which a novel item arises from a pre-existent domain: a novel (emergent) item comes into existence at a certain time as the result of previous events. In this case, the properties of a system at different times, t and t_1, are relevant. By contrast, in the synchronic case the time variable is irrelevant: emergence refers to the relationship between a certain item and a lower level: a novel (emergent) item arises from an underlying domain. In both cases, novelty is neither reducible nor predictable from the basal domain. In this article we will only be concerned with synchronic emergence, which carries with it the idea of a hierarchy of levels, where the higher levels emerge from the lower ones.

A second point to be stressed in the present context is the usual distinction between *epistemic* and *ontic* emergence (see O'Connor and Wong 2015). Epistemic emergence is not an ontic phenomenon, since it is subject to the limitation of human knowledge: it is such limitation what makes the emergent item neither explainable nor predictable from the basal level. Ontic emergence, by contrast, refers to the relationship between items belonging to different ontic levels, sometimes expressed in mereological terms: the emergent items, which arise from a lower level, are ontically new and populate reality as objectively as the items belonging to the lower level. Although the concept of epistemic emergence leads to very subtle and interesting discussions, in this article we will focus only on ontic emergence, which, we think, takes up the original idea of emergence in philosophy. Therefore, we will consider theories and inter-theoretic relations only as a clue for ontic claims.

Finally, a clarification about the ontological category of emergents. In the literature on the matter, it is mostly assumed, sometimes implicitly, that emergence is predicated of properties. However, other alternatives can be found as well (Schröder 1998). As our task in this article is insensitive to this issue, we will not restrict the application of the concept of emergence: in principle, we will admit the possibility of emergence of properties, substantial entities, laws as regularities in nature, events, processes, etc. In order to embrace all these cases, we will use the term '*item*' to denote whatever belonging to the realm of reality, without specifying its ontological category.

3 Emergence Versus Reduction

Emergence was traditionally understood as non-reductive: emergent items cannot be reduced to the basal level. Nevertheless, more recently, some authors have raised the novelty of claiming the compatibility between reduction and emergence (Butterfield 2011b). This view is in resonance with a neo-reductionist perspective that is gaining strength mainly in present-day philosophy of physics (see, e.g., Schaffner 2006; Dizadji-Bahmani et al. 2010; Butterfield 2011a; Sarkar 2015). Let us see this issue in more detail.

The classical locus of the analysis of reduction is Ernest Nagel's *The Structure of Science* (1961), where reduction is conceived as a logical relationship between theories: the reduced theory is a logical consequence of the reducing theory (condition of derivability) plus certain sentences that connect the terms of the reduced theory with the terms of the reducing one (condition of connectability). During the following years, the attempt to apply the model to concrete scientific situations led to weaken the requirements for reduction. Regarding derivability, Nagel himself (1970) accepted that the logical deduction of the reduced theory from the reducing theory may not always be possible: it may be the case that the reducing theory corrects the reduced one through approximations and other formal strategies quite far from logical deduction (see also Wimsatt 1976). Regarding connectability, Nagel (1970) also acknowledged that the links between reducing and reduced theory are typically factual assumptions: he called them 'bridge laws'.

Already since the 1970s, the applicability of the Nagelian model of reduction began to be severely criticized (see Hull 1972; Fodor 1974, 1975; Kitcher 1984). In particular, Hans Primas (1998) claimed that there are no significant and scientifically well-founded examples of the model (see also Scerri and McIntyre 1997; Rohrlich 1988, 1990). Maybe in order to deal with criticisms, recent years have witnessed a pronounced revival of reductionist perspectives (e.g. Fazekas 2009; Klein 2009; Dizadji-Bahmani et al. 2010, 2011; Needham 2010; Butterfield 2011a; van Riel 2011; Schaffner 2013). From this neo-reductionist perspective, weakening strategies were introduced into the original model. For instance, Foad Dizadji-Bahmani et al. (2010) move away from the spirit of Nagel's view by claiming that explanation is not a necessary condition for reduction: the aim of reduction is confined to consistency and confirmation. Jeremy Butterfield (2011a, b) considers that reduction admits the appeal to deduction after taking a limit of an appropriate parameter. In turn, Robert Batterman (2002) recalls that the limiting relations between theories are not always regular, but can be singular in many cases: the behavior in the limit differs significantly from the limiting behavior. Deepening the refinement that Nagel (1970) introduced to his model, Sahotra Sarkar (2015) argues that logical deduction must be replaced by a broader class of inferential techniques that allow for different types of approximation. In his detailed study of the relations between chemistry and physics from a reductionist stance, Hinne Hettema (2012) even accepts that reduction incorporates assumptions that are inadmissible from the viewpoint of the principles of the reducing theory. All these strategies, which make the original Nagelian model much more flexible, can be conceded because reduction is conceived as an inter-theoretic relation: if the task is to find a formal link between two theories, we are not confined to mere deduction; rather, there are a number of different resources we can appeal to. In fact, in many cases this is the way in which science works in practice in order to establish inter-theoretic connections.

Once it is accepted, as neo-reductionists do, that reduction is an inter-theoretic relationship and emergence is an ontic relationship, it turns out to be clear that there is no true (in principle) incompatibility: although the emergent item belongs to a genuinely new level with respect to the basal level, the formal link between the theories describing the two levels could be successfully established with the introduction of the appropriate resources. Naturally, if the concept of reduction is relaxed to such a large extent, one is entitled to ask why is the connection between theories still called 'reduction' instead of merely 'inter-theoretic link' (see Lombardi 2014a). And, in fact, it can be argued that a relaxed concept of reduction does not preserve much of the connotations of its Latin precursor, *reducere*: *re*, 'back again' + *ducere*, 'to bring', 'to lead'. Its original sense was 'to bring back', 'to restore'; this led to 'to bring to a different state'; then 'to bring to a simpler state'; and finally 'to diminish in size or amount'. At present, to reduce is to make smaller or less in amount, degree or size. Nothing is brought back, nor restored to a simpler state, nor diminished in size or amount, when the introduction of so many and so different tools to make reduction possible is admitted. Be as it may, the fact is that, pace logical positivism and contemporary neo-reductionism, in its origin, as old as philosophy itself, the very idea of reduction seems to have been ontic rather than epistemic. Already in the Pre-Socratic philosophy, the idea of a fundamental stuff (water, *apeiron*, air) which everything is made of was the trademark of the Milesian school (Thales, Anaximander, Anaximenes) in its search for reducing multiplicity to unity. And even when this initial monism was later abandoned in favor of an ontological picture based on a few material principles, the attempt to reduce the diversified empirical reality to a simpler underlying realm survived in Empedocles and his four elements (fire, air, water and earth) and in the atomism of Leucippus and Democritus (with their atoms and void). In the Modern Age, ontic reduction reappears in two scenarios. On the one hand, the assumption that secondary qualities, merely subjective, must be reduced to primary qualities, endowed with ontic priority, permeates the philosophy of Locke and the physics of Galileo. On the other hand, Ancient atomism, introduced in

Modern Europe by Gassendi, revives in Boyle's corpuscular philosophy, which, in turn, was a strong influence on later science, as Newton's corpuscular theory of light and Dalton's modern atomic theory. Nowadays, the idea of ontic reduction is still present in many areas of science; a paradigmatic example is the Standard Model of particle physics. In all these cases, a certain ontic domain is brought back to another domain conceived as fundamental; in turn, this reduces the number and/or the variety of genuine items in reality.

Despite the declared rejection of metaphysics by logical positivists, inter-theoretic reduction had an ontic motivation even for some of them: it was seen as desirable because it would help in the elaboration of a complete and ontically parsimonious picture of reality (Neurath 1935). Perhaps this idea of ontic reduction was behind Nagel's original insights about reduction; for instance, in his 1949 seminal work, he assumed that all the terms of the reduced theory must be *defined* in terms belonging to the reducing theory (Nagel 1949). If this kind of inter-theoretic reduction obtained, in principle everything that could be said with the reduced theory could also be said with the reducing one. In turn, theoretical elimination would supply good reasons to believe in ontic elimination; as Lawrence Sklar clearly says, "Light waves are not correlated with electromagnetic waves, for they *are* electromagnetic waves." (Sklar 1967, p. 120).

The relevance of ontic assumptions in the attempts of reducing one theory to another is also clear in the paradigmatic case studied in the discussions on the matter: the alleged reduction of thermodynamics to classical statistical mechanics. It is true that Boltzmann tried to explain thermal phenomena in gases in terms of classical mechanics and to reduce the second law to mechanical processes. However, his scientific effort was not motivated by the aim of simplicity, coherence or mere inter-theoretic explanation: Boltzmann's program was explicitly driven by the ontic assumption that gases are nothing else than particles in mechanical interaction. Another much less studied case is Maxwell's attempt to reduce electromagnetism to mechanics under the ontic belief that electromagnetic phenomena are nothing else than mechanical vibrations of a luminiferous aether. In both cases, the underlying ontic assumption was that all nature is made of mechanical entities governed by the laws of physics discovered by Newton; it was precisely this assumption what justified strategies directed to explain the new theories (thermodynamics, electromagnetism) by means of classical mechanics.

When we turn to ontic reduction (as the most meaningful and relevant sense of reduction), the traditionally claimed incompatibility between reduction and emergence becomes evident: if every real item belongs to a single fundamental ontic domain to which everything reduces, then emergent items cannot exist.[1] As advanced above, without minimizing the relevance of the discussion about inter-theoretic reduction, in the following sections we will only focus on ontic matters.

4 The General Notion of Emergence

The general notion of emergence is very appealing: in relation to the lower level domain from which they arise, emergents are usually characterized as novel, unpredictable, unexplainable and/or irreducible on the basis of said lower level domain. In Philip Anderson's

[1] For a different view, see Wimsatt (2000) and Mitchell (2012), where the compatibility between ontological reduction and emergence is argued for, but at the cost of turning to a more methodological sense of reduction and at the cost of making 'emergence' collapse with what some British emergentists would regard as 'resultant'.

terms, 'emergence' expresses the idea that the whole is not merely greater than but essentially different from the sum of the parts (Andersen 1972). But as soon as one tries to make this general idea more precise, multiple and very different views (along with multiple issues) arise. In this sense, Jaegwon Kim claims: "The term 'emergence' seems to have a special appeal for many people; it has an uplifting, expansive ring to it, unlike 'reduction' which sounds constrictive and overbearing. We now see the term being freely bandied about, especially by some scientists and science writers, with little visible regard for whether its use is underpinned by a consistent, tolerably unified, and shared meaning" (Kim 2006, p. 547).

Nevertheless, despite the many different meanings attached to the word 'emergence', there are several features shared by almost every position. Virtually all emergentists hold a *hierarchical view*, according to which reality is organized in different ontic levels or strata. Pace those recent claims about the compatibility between reduction and emergence, emergence is traditionally conceived as the symptom of a *failure of reduction*. Moreover, emergence is an essentially *asymmetric* relation: if *A* emerges from *B*, then *B* does not emerge from *A*. This means that emergence does not involve mere correlations, but requires something else: *ontic dependence*, that is, the fact that each level depends for its existence on the lower level. In other words, if *A* emerges from *B*, then if *B* didn't exist, *A* would not exist either.

Another salient feature of emergent items (at least, in many authors' views) is that they have *novel causal powers* or are causally autonomous, meaning that they are capable of producing genuinely novel effects that are not reducible to the causal powers of the basal level (if one prefers to avoid the talk about causal powers, it might be said that emergents are actively involved in new regularities in their ontic domain). This feature of emergent items can be traced back to the British tradition, e.g. Mill and Broad. For Kim (1999), the reason for endowing emergent items with causal efficacy in their own right is that this would ensure they are not to be merely epiphenomenal. The level at which such novel causal powers are exerted is matter of debate. Some authors would consider emergent items to be efficacious at their own level, while others have considered such causal efficacy to be exerted downwardly.

Downward causation (a term first appeared in Campbell 1974) consists in the emergents' capability of affecting the basal level from which they arise: not only do emergent have novel causal powers, moreover, such powers are not restricted to the emergent level and affect the basal one. This is yet another very problematic idea (one that could be seen as aggravating the issues entailed by emergence), but it has nevertheless received some attention in the philosophy of biology (e.g. Campbell 1974; Soto et al. 2008; Malaterre 2011) and in the philosophy of mind (see, e.g. some articles in Anderson et al. 2000; Velmans 2002; Ellis et al. 2009), as well as exerted some influence in the foundations of physics and of chemistry. For instance, according to Henry Stapp (2005), the role of the observer in contemporary physics supplies strong evidence for causal gaps in the physical world (see also Davies 2006); in turn, Robin Hendry finds signs of downward causation in chemistry (2006), specifically in the emergence of molecular structure from quantum mechanics (2010).

The main problem with downward causation is that it seems to violate of the principle of causal closure of the physical domain, inherent to physicalism, according to which every physical event has a sufficient physical cause (Kim 1992, 1996). Physicalism, this is, the belief that all which is real depends, more or less directly, on the fundamental features of the basal domain of physics, and that all real regularities depend on the fundamental regularities of the basal domain of physics, frees reality from spurious entelechies. However, it also endows the physical level with ontic priority over the remaining levels of reality, which naturally supports the theoretical priority of physics over other special sciences.

But then, if all the items belonging to the non-basal levels are realized by physical items, how can genuine novelty emerge? Physicalist emergentism seems to contradict the metaphysical principle that something cannot come from nothing (O'Connor 1994). As Alexandru Manafu clearly explains in the particular case of chemical items: "It is hard to miss the apparent tension between the two claims made in the preceding paragraphs. If chemical stuff is composed of nothing else except micro-physical stuff, how can one justify the belief that there are even such things as *chemical* properties, truths, or explanations as opposed to merely complex quantum-mechanical properties, truths, or explanations? Given the generality of physics, how can the autonomy of chemistry be preserved in a substantial way, i.e., how can chemistry be considered autonomous in a way which goes beyond historical or methodological autonomy? If physicalism is true, can we even speak of the ontological autonomy of chemistry, as opposed to a merely historical or methodological autonomy?" (Manafu 2011, p. 10).

For this reason, in the fields of the philosophy of physics and of chemistry, many authors prefer to leave downward causation aside and to try to make sense of emergentism without appealing to this notion. For instance, Batterman (2002) supplies an account of emergence that does not require downward causation; Manafu (2011), although analyzes the notion of downward causation, finally proposes a view of emergence that is completely unrelated to that notion. Be as it may, in the next sections we will follow this trend, insofar the argumentation will be quite independent of the notion of downward causation.

5 Two Types of Emergence

In the discussions about reduction, two other distinctions have commonly been introduced: that between domain-preserving and domain-combining reductions (Nickles 1973) and that between intra-level and inter-level reductions (Wimsatt 1976), which are related but not identical to the traditional Nagelian distinction between homogeneous and inhomogeneous reductions (see Sarkar 2015). Leaving the specific details aside, we want to point out that those distinctions take into account not only the relation of inter-theoretic reduction itself, but also the poles of the relation, in particular, the domains referred to by the theories involved in the relation. Nevertheless, similar or analogous distinctions were not introduced in the discussions about the notion of emergence, perhaps under the assumption that emergence always connects items belonging to different domains. Inspired by those distinctions in the analysis of reduction, our purpose here is to take into account the domains to which the items related by emergence belong.

In order to carry out this task, we will consider the theories that describe the different domains studied by science. But this does not mean that our interest is inter-theoretic relations per se. Rather, the appeal to theories is a way to count with a criterion to draw a distinction among domains that does not depend on metaphysical presuppositions about the structural organization of reality. In the same spirit, we will talk of "domains" and not of "strata" in order to remain neutral about an a priori hierarchical constitution of nature.

Let us consider two items I_1 and I_2, denoted by the terms t_1 and t_2, respectively, which belong to certain theories. Let us also suppose that I_2 emerges from I_1. Two cases can be distinguished:

- *Inter-domain emergence* The terms t_1 and t_2 belong to two different theories T_1 and T_2, respectively. From an ontic point of view, this means that the items I_1 and I_2 belong to different ontic domains, those referred to by the theories T_1 and T_2. So, the emergence of I_2 from I_1 expresses the fact that there is a relation of ontic dependence between the two domains, or at least between some items belonging to them.
- *Intra-domain emergence* The terms t_1 and t_2 belong to the same theory T. From an ontic point of view, this means that the items I_1 and I_2 belong to the same ontic domain, that referred to by the theory T. In this case, the emergence of I_2 from I_1 expresses the fact that two levels can be identified within the same domain, in such a way that the level corresponding to I_2 depends ontically on the level corresponding to I_1.

Each kind of emergence has its typical examples:

- The paradigmatic case of *inter-domain emergence* is the emergence of thermodynamic items from mechanical items, in particular, of temperature from the mechanical motion of particles or of irreversible thermodynamic behavior from the reversible basal dynamics. Another less analyzed but often mentioned case is that of the emergence of classical behavior from the underlying world described by quantum mechanics.
- A typical example of *intra-domain emergence* is the emergence of indeterministic and irreversible behavior from a deterministic and reversible dynamics in highly unstable classical systems. Another example usually not considered in the literature about emergence is the case of quantum decoherence: the irreversible loss of coherence that emerges from an underlying unitary evolution. In these cases, the relation of emergence is internal to the domain described by a certain theory. Nevertheless, certain properties and regularities that arise in a macro-level are missing in a lower micro-level, and may even be contradictory with those of the micro-level.

The distinction between intra-domain and inter-domain emergence is interesting for a number of reasons. For one thing, it brings the varieties of emergence closer to the varieties of reduction and, thus, it is useful for better analyzing the relation between these two concepts. But also, this distinction helps revealing the possibility (at very least, conceptual) that a certain intra-domain emergence in the basal domain is a necessary condition for inter-domain emergence. And in fact, there may be an example of such situation. For instance, in the context of the Gibbsian approach to statistical mechanics, the inter-domain emergence of thermodynamic irreversibility from the domain of irreversible mechanics requires (i) the intra-domain emergence of macro-irreversibility in the mechanical domain, and (ii) the conceptual identification between the mechanical macro-irreversibility so obtained with the thermodynamic irreversibility of the emergent domain. The fact that the link between thermodynamics and mechanics requires two conceptual steps was clearly acknowledged by Gibbs himself: first, he computed certain quantities for the canonical and microcanonical ensembles, and then he associated those quantities with certain thermodynamic quantities by means of "*thermodynamic analogies*" (see Gibbs 1902, Chapter 14, "Discussion of thermodynamic analogies"). As Jos Uffink notices: "He approaches this issue quite cautiously, by pointing out certain analogies between relations holding for the canonical and microcanonical ensembles and results of thermodynamics." (Uffink 2007, p. 994; see also Sklar 1993).

The possibility mentioned above goes completely unnoticed if the distinction between inter-domain and intra-domain emergence is not taken into account. However, drawing a conceptual distinction between two different types of emergence does not imply accepting both of them as genuine instances of emergence. This is precisely what will be discussed in the following sections.

6 Inter-Domain Emergence

The traditional arena of the debate between reductionists and emergentists is the relationship between the thermodynamic and the mechanical domains, that is, a situation that, if emergence holds, is a case of the inter-domain kind. Nevertheless, the scope of emergence may be conceived in two ways.

From the perspective of a strong form of inter-domain emergence, all the thermodynamic items, either individual objects, properties or processes, emerge from mechanical items. Not only are temperature and irreversibility emergents, but gases also emerge from mechanical particles. Analogously, not only do classical trajectories emerge from quantum behavior, but macroscopic bodies, as tables and planets, also emerge from the world of quantum mechanics. It is quite clear that ontic reductionists reject this strong emergence, since they conceive of reality as populated exclusively by the items belonging to the domain referred to by the more basic theory: the emergent items are only conceptual constructs, which may be pragmatically useful but do not refer to an ontic domain other than the one described by the "fundamental" theory.

However, there is a milder and more traditional form of inter-domain emergence, according to which entities belong to the basal domain and there can only be emergence of properties, processes and the regularities that involve those entities. Besides being the most common way of conceiving emergence, this perspective can be accepted by certain inter-theoretic neo-reductionists. For instance, in their detailed work of defense of inter-theoretic reduction, Dizadji-Bahmani et al. (2010) distinguish between two kinds of bridge laws, *entity association laws* and *property association laws*: "Entity association laws are different from property association laws both in content and in origin. Entity association laws indeed express identities: gases *are* swarms of molecules, genes *are* strings of amino acids [sic[2]], etc. The same does not hold for property association laws; these laws can, but need not express identities. […] The second difference is that, while property association laws are external to T_F [the reducing theory], entity association laws are internal to T_F." (2010, p. 404). The fact that properties do not need to be associated by means of identities leaves open the way to emergence. Nevertheless, by rejecting the existence of two different ontic domains, the believer in ontic reductionism would also reject this softer form of emergence: if reality is exhausted by the fundamental physical items, the emergence of properties would be something as magic as the existence of entelechies or *élan vital*.

Although this combination of monism of entities and emergence of properties is the most common way of conceiving inter-domain emergence, it is not unquestionable. On the one hand, logics teaches us that 'being a gas' and 'being a particle' can be conceived as referring to properties. Why should we accept, with Dizadji-Bahmani et al. that 'gas' and 'particle' refer to entities, whereas 'temperature' and 'kinetic energy' refer to properties? Of course, there is no conceptual obstacle to accept this semantic difference; however, it must be admitted that, even if usual, it is the result of a metaphysical decision, not supported by formal or empirical arguments. On the other hand, let us concede, for the sake

2 We take that the authors meant "*nucleic* acids".

of the argument, that the term ‘gas’ refers to an entity. Dizadji-Bahmani et al. tell us that the word ‘gas’ does not exclusively belong to thermodynamics: since the identity between ‘gas’ and ‘swarm of particles’ is internal to mechanics, ‘gas’ also belongs to mechanics with the same reference. But this implies that there is some way of identifying the reference of the term ‘gas’ *independently of the theories* in which it is involved. In other words, the identity of an entity as a gas is independent of and conceptually previous to any description. This conclusion has also a metaphysical flavor that might seem unpalatable to people with empiricist inclinations.

The above considerations lead us to notice that both the strongest version and the most traditional version of inter-domain emergence can also be rejected from a perspective diametrically opposite to reductionism: ontic pluralism. During the last decades, several ontic pluralist views have been proposed (e.g. Putnam 1981, 1990; Torretti 2000, 2008; El-Hani and Pihlström 2002; Lombardi and Labarca 2005; Lombardi 2014b): although the different versions differ in their fields of application and in their main philosophical inspirations, all of them agree on the rejection of the metaphysically realist position known as the perspective of God’s Eye, that is, the assumption of a neutral and privileged perspective from which reality can be described as it is in itself. According to ontic pluralism, our ontic domains are constituted as a synthesis between the *noumenal* reality and the categorical schemes implicit in our theories; such schemes acquire stability as a consequence of the pragmatic success of the theories that presuppose them. From this perspective, rooted both in Kantian philosophy and in American pragmatism, the metaphysical question about the existence of an item, independently of any theory and practice, makes no sense.

The idea of ontic pluralism was conceived mainly as a criticism of ontic reductionism, according to which the whole reality is embedded in a single ontic domain, precisely, that described by fundamental physics. Nevertheless, if ontic pluralism is consistently supported, one should also reject emergentism, even in its softer form. In fact, claiming that temperature emerges from a swarm of particles would require a neutral, external point of view that is neither the point of view of mechanics or thermodynamics. According to ontic pluralism, on the contrary, from this perspective, no metaphysical assumption about the structure of reality independent of any theory can be accepted: claiming an entity to be a gas without any reference to some theoretical framework makes no sense. Ontic pluralism implies that there is no external, neutral perspective from which reality can be described that would allow us to make such claims without reference to a particular theory. Therefore, a property belonging to an ontic domain cannot be properly attributed to an entity belonging to another domain where the property does not exist: temperature cannot be conceived as an emergent property of a swarm of particles belonging to the mechanical domain in a consistent manner.

Another point that ontic pluralism is forced to reject is the assumption of asymmetry inherent to emergentism. Given that the supposedly emergent domain turns out to be as constituted as the supposedly basal domain, and since, again, there is no external perspective from which reality in itself can be described, then no neutral viewpoint can be adopted to say that one of domain has ontic priority over the other. The emergentist might retort that asymmetry is not adopted due to a merely metaphysical motivation, but there are historical and/or pragmatic reasons for accepting it. Nevertheless, these argumentative strategies are not successful in supplying the desired support to asymmetry.

On the one hand, the history of science shows several cases where the replacement of the “basal” theory did not affect the theory describing the supposedly emergent domain. The paradigmatic example is the link between thermodynamics and the underlying theory at different historical times: this basal role was first played by caloric theory, then by classical mechanics and at present by quantum mechanics, and the involved inter-theoretic links changed accordingly. However, the "phenomenological" theory, macroscopic thermodynamics, remained unmodified during the entire historical process. Of course, this does not prove ontic independence. Nevertheless, if the fate of the theory describing the "emergent" domain is immune to the fate of the theory describing the "basal" domain, there seems to be no good philosophical reasons to assume the ontic dependence of the first one on the second (see Lombardi and Labarca 2006).

On the other hand, regarding the pragmatic reasons for the ontic independence of the supposedly emergent domain, chemistry supplies an excellent example. The practice of chemistry shows a wide scientific field where it is possible to develop a highly fruitful work without relying on physics, in particular, on quantum mechanics. From this pragmatic viewpoint, "molecular chemistry holds the winning card: its astonishing success in the manipulation of known substances and in the production of new substances is the best reason for accepting the existence of the entities populating its realm. In other words, we are entitled to admit the reality of the molecular world—inhabited by, among others, chemical orbitals, bonding, chirality, molecular shapes—on the basis of the impressive fruitfulness of molecular chemistry itself, independently of what physics has to say about that matter." (Lombardi and Labarca 2011, p. 74). As a consequence, not only the theoretical virtues of chemistry, but primarily its pragmatic virtues are the factors that, although not proving independence, play a decisive role in the arguments for the autonomy of the chemical domain (see also Lombardi 2014b).

Summing up, inter-domain emergence can be resisted from two opposite perspectives. Ontic reductionism considers that emergents are mere epistemic constructs since only the supposedly basal ontic domain exists. Ontic pluralism, on the contrary, denies the asymmetry that characterizes emergence, since conceives the different ontic domains as equally constituted and, in principle, autonomous from each other: if there are relations between domains, they are symmetric and do not presuppose or imply ontic priority.

7 Intra-Domain Emergence

In the case of intra-domain emergence, the relation of emergence links items belonging to a single ontic domain and, so, described by the same theory. This case, even if not deeply discussed in the philosophical literature on emergence, is very familiar in the discourse of science in the fields of complexity and instability.

Let us consider the case of highly unstable classical mechanical systems, where indeterminism and irreversibility are usually conceived as emergent from an underlying determinist and reversible dynamics. This is a case of intra-domain emergence, because the scenario is always the phase space representing the possible combinations of values of the mechanical variables of the system (e.g., the tree components of the position and of velocity of all the particles that compose the system). Nevertheless, in the same scenario, two types of characters can be defined:

- In the *micro-level*, micro-states are represented by points in the phase space, and micro-evolutions are represented by sequences of micro-states, that is, by trajectories.
- In the *macro-level*, macro-states are represented by regions of non-zero volume resulting from a coarse-graining partition of the phase space, and macro-evolutions are represented by sequences of macro-states.

In spite of the clear relation between the two levels, the micro-behavior and the macro-behavior are completely different, even contradictory (see Frigg 2007):

- In the *micro-level*, the micro-evolutions are completely deterministic, since ruled by the laws of classical mechanics, and reversible, since falling under the Liouville theorem of conservation of volume in the phase space.
- In the *macro-level*, if the system is sufficiently unstable—if it is a K-system—, the macro-evolutions are indeterministic: the only macro-states that are univocally determined are those that have zero probability or one independently of the macro-history of the system. In turn, under high instability—if the system is mixing—, the macro-evolutions are irreversible: any macro-state will evolve increasing its volume until covering the entire available region of phase space.

It is interesting to note that an analogous distinction between intra-theoretic levels can be found in quantum mechanics when considering decoherence. In the quantum domain, two kinds of states should be distinguished: the *quantum states* of closed systems, which evolve unitarily according to the von Neumann equation (or, in the particular case of pure states, to the Schrödinger equation), and the *reduced states* of open systems, which may follow non-unitary evolutions described by master equations. Maybe the reason why these two types of states were not sufficiently distinguished in the literature is that they are represented by the same kind of mathematical object in the Hilbert space formalism. Nevertheless, this mathematical feature stems from the formalism used to formulate the theory and, thus, a different situation could obtain by using other formalisms. For instance, it has been proved that quantum states and reduced states are represented by different kinds of density operators in the so-called quaternionic formulation of quantum mechanics (Masillo et al. 2009); hence, they can be distinguished also from a mathematical viewpoint. Moreover, it can be proven that a reduced state can also be conceived as a kind of coarse-grained state of a closed system, which disregards certain degrees of freedom considered as irrelevant (Fortin and Lombardi 2014). This result justifies the claims of Roland Omnès (2001, 2002), who has repeatedly stressed that decoherence is a particular case of the phenomenon of irreversibility.

The examples of intra-domain emergence are typical of what has been called '*supervenience*', a term first used in its philosophical sense by Donald Davidson (1970) in the field of the philosophy of mind. For two sets of properties, *A* (the supervenient set) and *B* (the subvenient set or supervenience base), *A* supervenes on *B* just in case two things cannot differ with respect to *A*-properties without also differing with respect to their *B*-properties. In other words, a difference in *A*-properties requires a difference in *B*-properties.[3] Although inter-domain supervenience was considered in some few cases—there cannot be an *A*-difference in things belonging to a domain D_1 without a *B*-difference in things belonging to a domain D_2 (Kim 1998)—, in general it is supposed that the *A*-properties and the *B*-properties are possessed by the very same kind of individuals. On the other hand, supervenience holds when

[3] Some have recently argued that supervenience is a symmetric relation (see for example McLaughlin and Bennett 2018). However, the way in which this is shown (by appealing to trivial cases or perfect correlation cases) misses an important point regarding the role of this notion in specific philosophical problems, namely, that it was developed to account for classical and paradigmatic cases of asymmetric relations: mental properties supervening on physical properties, and moral properties supervening on natural properties,

there is *multiple realizability*, that is, when the relation between the lower subvenient level and the higher supervenient level is many-to-one: a single property of the higher level can be realized by many different lower level properties. This is particularly clear in the case of the supervenience of indeterminism and irreversibility in highly unstable mechanical systems: a single macro-state, represented by a region of non-zero volume of the phase space, is realized by many different micro-states, represented by points in the phase space.

Although supervenience is usually associated to emergence, reductionists consider that supervenience is compatible with reduction or even that it is a case of reduction. In the inter-theoretic case, Butterfield (2011a, b) insists that supervenience is compatible with reduction since, as we have seen, the model of inter-theoretic reduction can be made flexible enough to admit many different types of formal connection between theories. From the ontic viewpoint, the reductionist argues that nothing over and above the properties belonging to the lower level exists in reality. For instance, even if a picture has Gestalt properties, "the picture and the properties reduce to the arrangement of light and dark pixels. They are nothing over and above the pixels." (Lewis 1994, p. 415). Therefore, to the extent that the ontic reductionist conceives supervenience as a kind of reduction, she would reject intra-domain emergence as we have characterized it.

Interestingly, in contrast to the agreement among ontic reductionists in rejecting supervenience as distinct from reduction, emergentists do not take a unique position regarding supervenience. Many authors consider that the concept of supervenience makes the notion of emergence precise. For instance, Hilary Putnam (1975) conceives supervenience as emergence because, given that it is possible that subvenient properties be different but supervenient properties be the same, it cannot be said that the latter reduce to the former in the sense that they describe the same features from a different perspective. In the same line, Brian McLaughlin (1997) defines emergence as supervenience of properties plus supervenient fundamental laws, and Alexander Rueger (2000) conceives emergence as supervenience defined in terms of stability or robustness. Other emergentists, however, are less prone to conceive of a close link between supervenience and emergence, since they consider that even if the emergent properties are novel, the higher level regularities in which they participate are still the mere result of lower level regularities and, therefore, therefore, supervenience is not sufficient for genuine emergence. From this perspective, the paradigmatic case—or even the only genuine case—of emergence is quantum entanglement (e.g., Humphreys 1997; Silberstein and McGeever 1999; Howard 2007). As a consequence, these emergentists would consider that intra-domain emergence as characterized here is not a genuine case of emergence.

However, supervenience may have a better reception from an ontic pluralist perspective. Unlike reductionists and the above-mentioned non-supervenient emergentists, a pluralist may consistently accept intra-domain emergence as supervenience since in this case the asymmetry of the relation is not imposed as a metaphysical assumption on two equally constituted domains. In the case of supervenience, the asymmetry obtains in the context of a single ontic domain as the result of multiple realizability. Therefore, ontic pluralism, whereas rejecting inter-domain emergence, can integrate intra-domain emergence. Nevertheless, in order to do so, an ontic pluralist must face the arguments of reductionists and of those emergentists who deny supervenience the status of emergence relation.

Footnote 3 (continued)

but not the other way around. It is in accordance with the spirit of the original cases of supervenience that we take this relation to be asymmetric.

8 Many-Base Emergence

As mentioned in the Introduction, mainly due to the preeminence of logical positivism and its derivations in the field of the philosophy of science, the idea of emergence was “forgotten” for several decades in mainstream philosophy. With the revival of the notion during the last decades, several works on the matter appeared in the specific literature, not only with the purpose of elucidating the concept of emergence, but also to study specific case studies in the special sciences. When these works are examined, one can realize that a number of reported examples (alleged cases of emergence) do not strictly fall under any of the two types considered in the previous sections.

One of the most discussed cases in relatively recent literature is that of phase transitions and, in this context, one of the preferred examples is that of superconductivity (Batterman 2002, 2011; Bangu 2009; Morrison 2012). A key feature of these cases is the so-called *universality*, that is, the fact that, although the macro-system is composed of micro-constituents, the emergent phenomena are insensitive to changes in the micro-physical base. For instance, in superconductivity, the macro-properties (infinite conductivity, flux quantization, etc.) are the same for all superconductors, which means that systems with different micro-structures can nevertheless display identical macro-behavior. If the universal macro-behavior does not change along the change of the micro-base, this means that it does not depend on *which* particular micro-processes occur at that base level. But this seriously challenges reductionism, which requires that each particular macro-behavior be the result of the particular micro-processes at the base level.

Margaret Morrison (2012) argues that universality in this sense can be taken as a type of multiple realizability: macro-level regularities are heterogeneously multiply realized by different bases. Nevertheless, she also notices that it is not a standard case of the multiple realizability inherent to supervenience: universality does not refer to the many-to-one relationship between the subvenient states and the supervenient states. Moreover, “[t]he claim so often associated with supervenience—there can be no *A* difference without a *B* difference (where *A* properties supervene on *B* properties)—is irrelevant here since once the system reaches the critical point and universal behavior (*A* properties) is dominant, information about micro-level structure (*B* properties) is simply lost.” (Morrison 2012, p. 165).

As stressed above, this type of universality is not a case of the traditional multiple realizability that is typical of supervenience. Nevertheless, it also involves a many-to-one relationship –not between states, but between many material bases and a single, universal behavior. For instance, systems that are materially different, such as various fluids and magnets, display the same macroscopic behavior in phase transition, in particular, transition from liquid to vapor phase in the case of fluids, or transition from ferromagnetic to paramagnetic phase near the critical temperature in the case of magnets. In this sense, this is a *many-base* multiple realizability that implies a particular case of inter-domain emergence, which might be called ‘*many-base emergence*.’

The many-base multiple realizability specific of this form of inter-domain emergence can be found in other situations as well, which are very different from phase transitions. For instance, by focusing on the relation between chemistry and physics, Manafu (2011) stresses that many chemical properties are defined *functionally*, that is, in terms of their efficient roles, and not in terms of their physical constitution. According to the author, functional properties in chemistry are genuinely emergent, and they supply good reasons to defend the autonomy of chemistry regarding physics. He finds the origin of the idea that a thing is defined by what it does, and not by what it consists of, in the works of Alan Turing (1950) devoted to the foundations of computer science and artificial intelligence. Manafu also acknowledges that there is a kind of multiple realizability involved in functional properties; nevertheless, he does not notice that he is referring to a many-base multiple realizability, which implies, as Morrison stresses, that the relevance of the features of the micro-level structure to the behavior of the macro-level is simply lost.

The many-base emergence so characterized is also found in the well-known distinction between computer hardware and computer software, which has also been used to explain the emergence of mind from brain (see, e.g. Block 1995). But independently of considerations in philosophy of mind, it is quite clear that the same software can be realized by very different hardware bases (hardware made of silicon, germanium, vacuum tubes, or valves). Moreover, computer software can be studied, and commonly is studied, by people who know almost nothing about computer hardware: this is possible because the domain of software has its own features and rules, which do not depend on the particular hardware that implements it. It is in this sense that it can be said that software does not reduce to hardware but emerges from it, as a case of many-base emergence.

Yet another case of many-base emergence can be found in traditional communication processes. In fact, the source and the destination of information as described by Shannon's theory of information are independent of the nature of their physical substratum: the states-letters of the source are not physical states but are implemented by physical states, which may be of an extremely varied nature. And the same can be said about the channel, which embodies the correlations between source and destination: it does not matter how those correlations are established and physically "materialized"; what only matters is that they link the states of the source and the states of the destination (see Lombardi et al. 2016). This means that the informational behavior of the devices involved in communication emerges from its physical substratum but does not reduce to it. And what makes that behavior genuinely emergent is the fact that it is described by a specific theory, which does not depend on the physical constitution of the physical systems that implement it.

It might even be thought that certain behaviors related to high instability, although intra-domain emergent when considered in the context of statistical mechanics, can also be conceived as cases of many-base inter-domain emergence: chaos, attractors, bifurcations, etc., can emerge in systems of completely different nature: in planetary, meteorological, electrical and quantum systems, among others, and even in systems studied by economics, sociology, and biology.

The ontic reductionist might insist in claiming that even these are cases of reduction, since the putative emergent domain is still constituted and determined by the base domain. For instance, she might argue that, if we could follow the behavior of all the electrons in the circuits of a computer, we would know the software's behavior, since there is nothing over and above the physical hardware. However, if consistently adopted, this view would prevent the reductionist to say that the same software runs on two computers made of different physical materials, say, silicon and germanium, since strictly speaking software does not exist as an item in the world.

From the opposite position, the ontic pluralist is also forced to deny that many-base multiple realizability be a symptom of emergence. For her, since the many-to-one relation applies to different domains, constituted by the frameworks implicit in different theories, and given that there is no "external" viewpoint from which the domains can be compared, there is no argument to support the ontic priority of one domain over the others. The ontic pluralist will consider that, even though relations between domains do hold, they are symmetric ontic relations that do not involve the preeminence of certain domains over others.

9 Conclusions

Despite the deep disagreements about the notion of emergence, it cannot be denied that it is a very appealing notion, as evidenced by the fact that discussions around it have been going on for almost a century and continue up to our days. In this article, our purpose was not to argue for a definite position about the matter, but to introduce certain distinctions that may help organizing the debate and revealing interesting relations between concepts (types of emergence, types or reductionism, supervenience, etc.) and stances (reductionism, pluralism). To begin with, we pointed out that emergence is eminently an ontic notion; therefore, in principle, there is no obstacle to its compatibility with a sufficiently weak notion of inter-theoretic reduction. Nevertheless, we took comparisons worth studying to be those between emergence and other ontic notions, such as ontic reduction or ontic pluralism. Next, we introduced the distinction between inter-domain and intra-domain emergence, and considered how these two forms of emergence should be assessed from other ontic positions. Finally, we identified two different forms of inter-domain emergence, one of them based on a kind of many-base multiple realizability, which is usually not distinguished from the "common" multiple realizability responsible for inter-domain emergence.

While most literature on emergence focuses either on discussing, evaluating and comparing particular contributions or accounts of emergence, or on assessing a particular case study, here we aimed at stressing the relevance of the distinctions we have introduced when attempting to argue for or against emergence *in the first place*. Hopefully, this analysis will contribute to understanding the possible links between the notion of emergence and major ontological viewpoints.

References

Andersen, P. W. (1972). More is different. *Science, 177,* 393–396.

Anderson, P., Emmeche, C., Finnemann, N., & Christiansen, P. (Eds.). (2000). *Downward causation: Minds, bodies, and matter*. Aarhus: Aarhus University Press.

Bangu, S. (2009). Understanding thermodynamic singularities: Phase transitions, data, and phenomena. *Philosophy of Science, 76,* 488–505.

Batterman, R. (2002). *The devil in the details*. Oxford: Oxford University Press.

Batterman, R. (2011). Emergence, singularities and symmetry breaking. *Foundations of Physics, 41,* 1031–1050.

Block, N. (1995). The mind as the software of the brain. In D. Osherson, L. Gleitman, S. Kosslyn, S. Smith & S. Sternberg (Eds.), *Invitation to cognitive science* (pp. 170–185). Cambridge, MA: MIT Press.

Butterfield, J. (2011a). Emergence, reduction and supervenience: A varied landscape. *Foundations of Physics, 41,* 920–959.

Butterfield, J. (2011b). Less is different: Emergence and reduction reconciled. *Foundations of Physics, 41,* 1065–1135.

Campbell, D. T. (1974). Downward causation in hierarchically organised biological systems. In F. J. Ayala & T. Dobzhansky (Eds.), *Studies in the philosophy of biology: Reduction and related problems* (pp. 179–186). London/Basingstoke: Macmillan.

Cunningham, B. (2001). The reemergence of 'emergence'. *Philosophy of Science, 68,* S62–S75.

Darden, L., & Maull, N. (1977). Interfield theories. *Philosophy of Science, 44*(1), 43–64.
Davidson, D. (1970). Mental events. In L. Foster & J. W. Swanson (Eds.), *Experience and theory* (pp. 79–101). Amherst, MA: The University of Massachusetts Press.
Davies, P. (2006). The physics of downward causation. In P. Clayton & P. Davies (Eds.), *The re-emergence of emergence. The emergentist hypothesis from science to religion* (pp. 35–52). Oxford: Oxford University Press.
Dizadji-Bahmani, F., Frigg, R., & Hartmann, S. (2010). Who is afraid of Nagelian reduction? *Erkenntnis, 73,* 393–412.
Dizadji-Bahmani, F., Frigg, R., & Hartmann, S. (2011). Confirmation and reduction: A Bayesian account. *Synthese, 179,* 321–338.
El-Hani, C. N., & Pihlström, S. (2002). Emergence theories and pragmatic realism. *Essays in Philosophy, 3,* 3.
Ellis, G., Murphy, N., & O'Connor, T. (Eds.). (2009). *Downward causation and the neurobiology of free will*. New York: Springer.
Fazekas, P. (2009). Reconsidering the role of bridge laws in inter-theoretic reductions. *Erkenntnis, 71,* 303–322.
Fodor, J. A. (1974). Special sciences (or: The disunity of sciences as a working hypothesis). *Synthese, 28,* 97–115.
Fodor, J. A. (1975). *The language of thought*. Cambridge, MA: Harvard University Press.
Fortin, S., & Lombardi, O. (2014). Partial traces in decoherence and in interpretation: What do reduced states refer to? *Foundations of Physics, 44,* 426–446.
Frigg, R. (2007). A field guide to recent work on the foundations of thermodynamics and statistical mechanics. In D. Rickles (Ed.), *The Ashgate companion to the new philosophy of physics* (pp. 99–196). London: Ashgate.
Gibbs, J. W. (1902). *Elementary principles in statistical mechanics*. New Haven: Yale University Press.
Hendry, R. F. (2006). Is there downward causation in chemistry? In D. Baird, E. Scerri & L. McIntyre (Eds.), *Philosophy of chemistry. Synthesis of a new discipline; Boston Studies in the Philosophy and History of Science* (Vol. 242, pp. 173–189). Dordrecht: Springer.
Hendry, R. F. (2010). Ontological reduction and molecular structure. *Studies in History and Philosophy of Modern Physics, 41,* 183–191.
Hettema, H. (2012). *Reducing chemistry to physics. Limits, models, consequences*. Groningen: Rijksuniversiteit Groningen.
Howard, D. (2007). Reduction and emergence in the physical sciences: Some lessons from the particle physics and condensed matter debate. In N. Murphy & W. R. Stoeger (Eds.), *Evolution and emergence. Systems, organisms, persons* (pp. 141–157). Oxford: Oxford University Press.
Hull, D. L. (1972). Reductionism in genetics-biology or philosophy? *Philosophy of Science, 39,* 491–499.
Humphreys, P. (1997). How properties emerge. *Philosophy of Science, 64,* 1–17.
Humphreys, P. (2008). Synchronic and diachronic emergence. *Minds and Machines, 18,* 431–442.
Kim, J. (1992). 'Downward causation' in emergentism and nonreductive materialism. In A. Beckermann, H. Flohr & J. Kim (Eds.), *Emergence or reduction? Essays on the prospects of nonreductive physicalism* (pp. 119–138). Berlin: Walter de Gruyter.
Kim, J. (1996). *Philosophy of mind*. Boulder: Westview Press.
Kim, J. (1998). The mind-body problem after fifty years. In A. O'Hear (Ed.), *Current issues in philosophy of mind* (pp. 3–21). Cambridge: Cambridge University Press.
Kim, J. (1999). Making sense of emergence. *Philosophical Studies, 95,* 3–36.
Kim, J. (2006). Emergence: Core ideas and issues. *Synthese, 151,* 547–559.
Kitcher, P. (1984). 1953 and all that: A tale of two sciences. *Philosophical Review, 93,* 335–373.
Klein, C. (2009). Reduction without reductionism: A defence of Nagel on connectability. *The Philosophical Quarterly, 59,* 39–53.
Lewis, D. (1994). Reduction of mind. In S. Guttenplan (Ed.), *A companion to the philosophy of mind* (pp. 412–431). Oxford: Blackwell.
Lombardi, O. (2014a). Linking chemistry with physics: Arguments and counterarguments. *Foundations of Chemistry, 16,* 181–192.
Lombardi, O. (2014b). The ontological autonomy of the chemical world: Facing the criticisms. In E. Scerri & L. McIntyre (Eds.), *Philosophy of chemistry. Growth of a new discipline; Boston Studies in the Philosophy and History of Science* (pp. 23–38). Dordrecht: Springer.
Lombardi, O., Holik, F., & Vanni, L. (2016). What is Shannon information? *Synthese, 193,* 1983–2012.
Lombardi, O., & Labarca, M. (2005). The ontological autonomy of the chemical world. *Foundations of Chemistry, 7,* 125–148.

Lombardi, O., & Labarca, M. (2006). The ontological autonomy of the chemical world: A response to Needham. *Foundations of Chemistry, 8,* 81–92.
Lombardi, O., & Labarca, M. (2011). On the autonomous existence of chemical entities. *Current Physical Chemistry, 1,* 69–75.
Malaterre, C. (2011). Making sense of downward causation in manipulationism: Illustrations from cancer research. *History and Philosophy of the Life Sciences, 33,* 537–562.
Manafu, A. (2011). *Emergence and reduction in science. A case study*. Ph.D Thesis, School of Graduate and Postdoctoral Studies, University of Western Ontario.
Masillo, F., Scolarici, G., & Sozzo, S. (2009). Proper versus improper mixtures: Towards a quaternionic quantum mechanics. *Theoretical and Mathematical Physics, 160,* 1006–1013.
McLaughlin, B. (1992). The rise and fall of British emergentism. In A. Beckermann, H. Flohr & J. Kim (Eds.), *Emergence or reduction? Essays on the prospects of nonreductive physicalism* (pp. 49–93). New York: de Gruyter.
McLaughlin, B. (1997). Emergence and supervenience. *Intellectica, 2,* 25–43.
McLaughlin, B., & Bennett, K. (2018). Supervenience. In E. N. Zalta (Ed.), *The stanford encyclopedia of philosophy* (Spring 2018 Edition). https://plato.stanford.edu/archives/spr2018/entries/supervenience/.
Mitchell, S. (2012). Emergence: Logical, functional and dynamical. *Synthese, 185,* 171–186.
Morrison, M. (2012). Emergent physics and micro-ontology. *Philosophy of Science, 79,* 141–166.
Nagel, E. (1949). The meaning of reduction in the natural sciences. In R. C. Stauffer (Ed.), *Science and civilization* (pp. 99–135). Madison: University of Wisconsin Press.
Nagel, E. (1961). *The structure of science. Problems in the logic of scientific explanation*. New York: Harcourt, Brace & World.
Nagel, E. (1970). Issues in the logic of reductive explanations. In H. E. Kiefer & M. K. Munits (Eds.), *Mind, science and history* (pp. 117–137). Albany, NY: State University of New York Press.
Needham, P. (2010). Nagel's analysis of reduction: Comments in defense as well as critique. *Studies in History and Philosophy of Modern Physics, 41,* 163–170.
Neurath, O. (1935). The unity of science as a task. In M. Neurath & R. S. Cohen (Eds.), *Otto Neurath: Philosophical papers 1913–1946* (pp. 115–120). Dordrecht: Reidel.
Nickles, T. (1973). Two concepts of intertheoretic reduction. *Journal of Philosophy, 70,* 181–201.
O'Connor, T. (1994). Emergent properties. *American Philosophical Quarterly, 31,* 91–104.
O'Connor, T., & Wong, H. Y. (2015). Emergent properties. In E. N. Zalta (Ed.), *The stanford encyclopedia of philosophy* (Summer 2015 Edition). http://plato.stanford.edu/archives/sum2015/entries/properties-emergent/.
Omnès, R. (2001). Decoherence: An irreversible process. *Los Alamos National Laboratory*, arXiv:quant-ph/0106006.
Omnès, R. (2002). Decoherence, irreversibility and the selection by decoherence of quantum states with definite probabilities. *Physical Review A, 65,* 052119.
Primas, H. (1998). Emergence in exact natural sciences. *Acta Polytechnica Scandinavica, 91,* 83–98.
Putnam, H. (1975). Philosophy and our mental life. In *Mind, language, and reality: Philosophical papers* (pp. 291–303). Cambridge: Cambridge University Press.
Putnam, H. (1981). *Reason, truth and history*. Cambridge: Cambridge University Press.
Putnam, H. (1990). *Realism with a human face*. Cambridge, MA: Harvard University Press.
Rohrlich, F. (1988). Pluralistic ontology and theory reduction in the physical sciences. *The British Journal for the Philosophy of Science, 39,* 295–312.
Rohrlich, F. (1990). There is good physics in theory reduction. *Foundations of Physics, 20,* 1399–1412.
Rueger, A. (2000). Physical emergence, diachronic and synchronic. *Synthese, 124,* 297–322.
Sarkar, S. (2015). Nagel on reduction. *Studies in History and Philosophy of Science, 53,* 43–56.
Scerri, E., & McIntyre, L. (1997). The case for the philosophy of chemistry. *Synthese, 111,* 213–232.
Schaffner, K. F. (2006). Reduction: The Cheshire cat problem and a return to roots. *Synthese, 151,* 377–402.
Schaffner, K. F. (2013). Ernest Nagel and reduction. *Journal of Philosophy, 109,* 534–565.
Schröder, J. (1998). Emergence: Non-deducibility or downwards causation? *The Philosophical Quarterly, 48,* 433–452.
Silberstein, M., & McGeever, J. (1999). The search for ontological emergence. *The Philosophical Quarterly, 49,* 182–200.
Sklar, L. (1967). Types of inter-theoretic reduction. *The British Journal for the Philosophy of Science, 18,* 109–124.
Sklar, L. (1993). *Physics and chance*. Cambridge: Cambridge University Press.
Soto, A. M., Sonnenschein, C., & Miquel, P. (2008). On physicalism and downward causation in developmental and cancer biology. *Acta Biotheoretica, 56,* 257–274.

Stapp, H. (2005). Quantum interactive dualism: An alternative to materialism. *Journal of Consciousness Studies, 12,* 43–58.
Torretti, R. (2000). Scientific realism and scientific practice. In E. Agazzi & M. Pauri (Eds.), *The reality of the unobservable. Observability, unobservability and their impact on the issue of scientific realism* (pp. 113–122). Dordrecht: Kluwer.
Torretti, R. (2008). Objectivity: A Kantian perspective. In M. Massimi (Ed.), *Kant and philosophy of science today* (pp. 81–95). Cambridge: Cambridge University Press.
Turing, A. (1950). Computing machinery and intelligence. *Mind, 59,* 433–460.
Uffink, J. (2007). Compendium of the foundations of classical statistical physics. In J. Butterfield & J. Earman (Eds.), *Philosophy of physics* (pp. 923–1074). Amsterdam: Elsevier.
van Riel, R. (2011). Nagelian reduction beyond the Nagel model. *Philosophy of Science, 78,* 353–375.
Velmans, M. (2002). How could conscious experiences affect brains? *Journal of Consciousness Studies, 9,* 3–29.
Wimsatt, W. C. (1976). Reductive explanation: A functional account. In R. S. Cohen, C. A. Hooker & A. C. Michalos (Eds.), *PSA 1974: Proceedings of the 1974 Meeting of the Philosophy of Science Association* (pp 671–710). Dordrecht: Reidel.
Wimsatt, W. C. (2000). Emergence as non-aggregativity and the biases of reductionisms. *Foundations of Science, 5,* 269–297.

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