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Emergence: A pluralist approach

(Emergencia: Un enfoque pluralista)

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ABSTRACT: Despite the common use of the concept of emergence, no uncontroversial theoretical framework has been yet formulated in this regard. In this paper, I examine what this circumstance suggests about the significance and usefulness of this concept. I first trace a brief history of the notion of emergence from its first formulation among the British Emergentists to its contemporary uses. Then, I outline its most common features and examine three examples of emergent phenomena, namely particle decay, free will, and division of labour in ant colonies. These three cases of emergence exhibit different features and imply criteria which only partially overlap. I then suggest that the multiplicity of features and criteria recognised as defining emergence, rather than being a threat to the tenability of the concept, should encourage the assumption of a pluralist attitude that is consistent with both the employment of this idea in different sciences and the recognition of emergent phenomena across different levels of organisation. Finally, I propose that emergence can be approached in a similar way to how Richard Boyd approached the problem of natural kinds, namely by identifying an open cluster of properties, rather than a set of necessary and sufficient conditions.

KEYWORDS: emergence; emergentism; reduction; pluralism; cluster theory.

RESUMEN: *A pesar del uso común del concepto de emergencia, todavía no se ha formulado ningún marco teórico incontrovertible al respecto. En este artículo examino lo que esta circunstancia sugiere sobre el significado y la utilidad de este concepto. En primer lugar, trazo una breve historia de la noción de emergencia desde su primera formulación entre los emergentistas británicos hasta sus usos contemporáneos. En segundo lugar, esbozo sus características más comunes y examino tres ejemplos de fenómenos emergentes, a saber, la desintegración de partículas, el libre albedrío y la división del trabajo en las colonias de hormigas. Estos tres casos de emergencia presentan características diferentes e implican criterios que solo coinciden parcialmente. En tercer lugar, sugiero que la multiplicidad de rasgos y criterios reconocidos como definitorios de la emergencia, en lugar de constituir una amenaza para la sostenibilidad del concepto, debería fomentar la asunción de una actitud pluralista que será coherente tanto con el empleo de esta idea en distintas ciencias como con el reconocimiento de fenómenos emergentes en distintos niveles de organización. Por último, propongo que la emergencia puede abordarse de forma similar a como Richard Boyd abordó el problema de los tipos naturales, es decir, identificando un conjunto abierto de propiedades, en lugar de un conjunto de condiciones necesarias y suficientes.*

PALABRAS CLAVE: emergencia; reducción; pluralismo; teoría de los clúster.

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1. Introduction: the Age of Emergence

In *A Different Universe* (2005), physicist Robert Laughlin suggests that though reductionism has dominated the natural sciences for decades, there are now good reasons to move from the "age of reductionism" to that of emergence. This thesis was reiterated by Carl Gillett in his *Reduction and Emergence in Science and Philosophy* (2016), and is consistent with the strong need, highlighted by Sandra Mitchell's works (2003, 2009), to integrate reductive strategies in the understanding and modelling of nature with a more complex and multidimensional epistemology. As pointed out by Mitchell, reductive approaches can be successful, but not every natural phenomenon can be adequately modelled in this way: "Physics is a domain in which a reduction of complex phenomena to simpler ones has been particularly successful. However, many complex behaviors in biological and social sciences seem not to yield as well to a reductive approach" (Mitchell, 2009, p. 2; see also Wuppuluri & Stewart, 2022).

Indeed, the weakening of the reductionist view seems supported by the recent diffusion, among both philosophers and scientists, of a sort of alternative approach employing the notion of emergence in the description of a vast array of natural phenomena.[1] The main difficulty related to emergentist descriptions, however, is their ambiguity. Despite being invoked in several cases, no uncontroversial theoretical framework has been yet formulated about emergence, and there is no consensus in the scientific and philosophical world about its precise meaning, methodological value, and exact potential (Bedau & Humphreys, 2008; Gibb, Hendry & Lancaster, 2019). In other terms, saying that a phenomenon is emergent without further considerations about the particular meaning of this attribution provides some suggestive but indeterminate ideas about it. The question, at this point, is what this circumstance suggests about the significance and usefulness of this concept, and this is the issue the present paper aims to address.

In the next paragraphs, I will first trace a brief history of the notion of emergence from its first formulations among the British Emergentists to its contemporary uses. I will then outline what might be seen as its most common features and examine three examples of emergent phenomena. The first, described by Paul Humphreys, involves particle decay; the second, examined by Jessica Wilson, involves free will; the third, described —among others— by Sandra Mitchell, regards division of labour in ant colonies. I chose these case studies because they belong to very different ontological domains and are analysed by different disciplines. These three case studies of emergence exhibit different features and imply criteria which only partially overlap. Finally, I will suggest that the multiplicity of features and criteria recognized as defining emergence, rather than being a threat to the tenability of the concept, should encourage us to assume a pluralist attitude that is consistent with both the employment of this idea in different sciences and the recognition of emergent phenomena across different levels of organisation.

[1] Examples include spacetime (Bain, 2013; Crowther, 2016; Wüthrich, 2019), quantum entanglement (Humphreys, 1997, 2016; Kronz & Tiehen, 2002; Hüttemann, 2005), superconductivity or ferromagnetism (Laughlin, 2005; Batterman, 2011; Crowther, 2016), molecular structure and molecular macroscopic properties (Luisi, 2002; Hendry, 2006; Scerri, 2008), stigmergy, flocking, or similar coordinated behaviours in insects, birds, fishes, and mammals (Grassé, 1959; Bonabeau, Dorigo & Theraulaz, 1999; Mitchell, 2003; Cucker & Smale, 2007).

2. *From British to contemporary emergentism*

The first wave of interest in the concept of emergence can be traced back to the thinkers that Brian McLaughlin defined as "British Emergentists":

> This tradition began in the middle of the nineteenth century and flourished in the first quarter of this century. It began with John Stuart Mill's *System of Logic* (1843), and traced through Alexander Bain's *Logic* (1870), George Henry Lewes's *Problems of Life and Mind* (1875), Samuel Alexander's *Space, Time, and Deity* (1920), Lloyd Morgan's *Emergent Evolution* (1923), and C. D. Broad's *The Mind and Its Place in Nature* (1925) (1992, p. 49).

Despite it being somehow appropriate to unify these thinkers under a single label, the use they made of the concept of emergence was varied. While Lewes (1875), for instance, developed an account of emergence that is epistemic and correlated to an insufficiency of knowledge of the natural world, Morgan (1923) and Alexander (1920) suggested a properly ontological account of emergence, emphasizing the ability of emergent phenomena to exhibit novel causal efficacy. Despite these differences, however, what British Emergentists had in common was the commitment towards a monist view of the world, namely a metaphysical thesis known as "substance monism" whereby everything in the world is exhaustively composed of just *one kind* of substance. In particular, the British Emergentists shared the opinion that reality is composed of physical matter without the addition of any further non-physical element —no spirits, transcending substances, entelechies, or other metaphysically controversial entities. The first feature characterising an emergentist understanding of reality, therefore, is *monism*. Emergentism originated within a naturalistic —today we could even say "physicalist"— framework and rejected metaphysical forms of dualism or pluralism of the Cartesian or Bergsonian type.

The British Emergentists were also aware that admitting physical matter alone would open complex problems about the ontological autonomy of apparently non-material phenomena such as life and mind. For this reason, they highlighted that despite being exhaustively composed of physical constituents, these phenomena acquire novel properties as a consequence of their structure and organisation. The second feature characterising emergence, therefore, is *novelty*.

The third feature, *irreducibility*, requires a little digression. The diffusion of emergentist theories between the 19th and 20th centuries significantly coincided with a historical phase in which physics, chemistry, and biology led partially autonomous existences and their unification —however desired— was still far from being achieved. It was mainly the alleged possibility of this unification, which became more tangible in the 1920s, that caused the fall of British Emergentism. According to McLaughlin, the development of quantum mechanics, the explanation of chemical properties through electromagnetism, and the discovery of the molecular structure of DNA paved the way to a general thesis, namely that any natural phenomenon could sooner or later be accounted for by a "micro-explanation" —i.e., "the explanation of the behaviours of macro-systems in terms of the behaviours of their micro-constituents" (Hüttemann, 2004, p. 24). The supposed availability of micro-physicalist explanations for every macro-phenomenon thus coincided with the rejection of the emergentist hypothesis, and this clarifies the purely empirical nature of the debate in which British Emergentists were involved. Given some natural phenomena that

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could not be explained by physics, it seemed reasonable to hypothesise the existence and causal efficacy of new emergent natural structures and forces. However, the scientific discoveries of the early 20th century gave ample evidence to the idea that the root causes of various phenomena could be explained through classical physical principles, severely undermining the theoretical foundations of British Emergentism.

While in the 19th and early 20th centuries the progress of science weakened the theory of emergence by reinforcing (micro)reductionism, it was still science that favoured the return and strengthening of the former starting from the 1970s. In this respect, a well-known contribution came from the paper *More is different*, published in 1972 by physicist Philip W. Anderson. The author wrote: "I believe that at each level of organisation, or of scale, types of behaviour open up which are entirely new", adding that "surely there are more levels of organization between human ethology and DNA than there are between DNA and quantum electrodynamics, and each level can require a whole new conceptual structure" (1972, p. 396). As Anderson pointed out, the proliferation of scientific fields, as well as the discovery and classification of new natural phenomena, has only grown over time, not decreased, suggesting that the more we delve into reality, the more we uncover and the greater our need for diverse theories and models. This seems to encourage an emergentist, or at least pluralist, stance towards science, rather than a reductionist attitude aimed at unifying the multiplicity of scientific approaches in a single "privileged level of discourse" (Mitchell, 2003, p. 1). Another example of this comes from the British ethologist William Homan Thorpe, who suggested that while reductionism is an important methodology which *analyses* natural phenomena in the etymological sense of "decomposing them into their parts" ("analysis" derives from the Greek word ἀναλύω which means "breaking up, loosening, decomposing"), science requires *synthesis* as well, namely "to look for 'wholes'" (Thorpe, 1974, p. 110). In other words, besides studying the components of a system, science must also focus on the emergent constraints that harness the laws of chemistry and physics to fulfil higher-level functions. According to Thorpe, the idea of emergence is of critical importance in this respect, because it entails that there are "features in the world which could not be satisfactorily dealt with by a reductive process" (*ibid.*). The third feature characterising emergence, therefore, is *irreducibility*.

More generally, the recent interest in the notion of emergence can be related to the development of complexity studies (Mitchell, 2012). Complex systems science became a recognisable discipline at the end of the 20th century, even if important predecessors can be already found in the 1940s and 1960s, such as cybernetics (Wiener, 1948), or the General System Theory (von Bertalanffy, 1968). All these disciplines shared a common goal: finding general principles to explain how the simple local dynamics of systems composed of material parts can produce sophisticated and often universal macroscopic behaviours (Mitchell, 2009: xii). Core explanatory concepts included feedback loop, homeostasis, self-organisation, and emergence, where the latter frequently characterised —and still does— the macroscopic and organised behaviour arising from the microdynamics of the system.

Despite the popularity of the term "emergence" and the vast scope of its application, however, it still remains somehow shrouded in mystery, given that there is no single definition appropriate to all the contexts in which it is employed. Moreover, the three features that are usually connected with it —monism, novelty, and irreducibility— are too broad to provide a precise characterisation. While substance monism seems quite clear, irreducibility can be at least of two different kinds (i.e., ontological and epistemological), and in both cases the reductive strategies are more than one.[2] As for novelty, the same problem arises. Many features can be related to emergent novelty, and they are remarkably different from one another.[3] Moreover, it is possible to analyse emergence as both a state and a process, formulating models of emergence that are respectively synchronic or diachronic.

The three cases of emergence described in the next paragraphs —particle decay, free will, and division of labour in ant colonies— will exemplify what just stated. For now, it might be already suggested that while the plasticity of the notion of emergence can be viewed as a problem (Kim, 2006; O'Connor, 2006; Ladyman *et al.,* 2007; Silberstein, 2009; Taylor, 2015; Wilson, 2021), an alternative stance may be a healthy pluralism. In other words, despite the invariance of the term and the efforts undertaken by many authors to formulate comprehensive and univocal models of emergence, one might advance the hypothesis that emergence describes different natural phenomena that are characterised in different ways in different contexts, and this fact naturally justifies the tenability of different criteria and the relevance of different features. Adapting Sandra Mitchell's statement about complexity to emergence: "The multiplicity of definitions of 'emergence' reflects not confusion on the part of philosophers but the actual variety of ways that properties and behaviours are emergent".[4]

3. Particle decay. An example of Transformational emergence

The first case of emergence that I would like to examine is addressed by Paul Humphreys (1997, 2016). In *Emergence. A Philosophical Account* (2016), Humphreys draws a complex taxonomy of emergent phenomena and recognises five categories to describe them. Emergence can be (i) ontological, (ii) inferential, (iii) conceptual, (iv) synchronic, and/or (v) diachronic.

Very briefly, (i) ontological emergence is related to the appearance of genuinely *novel* properties of the world. These properties are distinct from the properties from which they

[2] Ontological reductions can be performed through a successful material decomposition entailing some sort of atomism (Humphreys, 2016). Another option is to illustrate the presence of exhaustive dependence relationships such as supervenience (Kim, 1999) or realization (Shoemaker, 2007), which in turn entails some kind of functionalism. Epistemological reductions, on the other hand, can be performed through a successful intertheoretic reduction —of which there are many versions (Nagel, 1961, 1970; Sklar, 1967)— or through reductions in the limit (Nickles, 1973; Chibbaro, Rondoni & Vulpiani, 2014). All these reductive strategies are related to opposite but correspondent forms of irreducibility, so just saying that a phenomenon is irreducible is not enough to understand how and why that is.

[3] Novelty can be related to non-linearity (Bedau, 1997), to qualitative novelty (Morgan, 1923/2013; Chalmers, 2006) (e.g., the novelty exhibited by *qualia*), to fundamentality (Barnes, 2012; Wilson, 2021) or to the presence of novel causal powers, profiles or, more generally, contributions (O'Connor, 1994; Kim, 1999; Wilson, 2021). Again, recognising the presence of some sort of novelty in a phenomenon is vague and explanatorily weak.

[4] The original sentence is the following: "The multiplicity of definitions of 'complexity' reflects not confusion on the part of scientists but the actual variety of ways that systems are complex" (Mitchell, 2003, p. 4).

emerge, and our knowledge about the system in which they appear is irrelevant to their existence.[5] (ii) Inferential emergence is just related to *unpredictability* and *underivability*. A clear way to frame this point is provided by Jaegwon Kim, who distinguishes between *inductive* and *theoretical* predictability (1999, p. 8) and states that even emergent phenomena can be predicted, but only inductively and not deductively.[6] (iii) Conceptual emergence concerns properties that are defined as emergent because the elaboration of new conceptual frameworks is required to explain them. Every special science property is an example of —at least— conceptual emergence, for different domains need different theoretical frames.

As for the temporal characterisation, Humphreys provides a distinction between (iv) synchronic emergence, in which higher- and lower-level phenomena coexist at the same time, and (v) diachronic emergence, in which the temporal evolution of the system is of primary importance since the occurrence of emergence depends on the processes that affected it at previous stages.

Given the particular attention paid to mental states as ideal cases of higher-level phenomena, philosophers and metaphysicians have generally focused on synchronic emergence. Still, in Humphreys' opinion, this attitude hinders an appropriate understanding of the phenomenon, given that real systems always have a temporal evolution that determines their properties.

As a case in point of ontological and diachronic emergence,[7] Humphreys describes particle decay.

The Standard Model is the theory that describes fundamental particles and three of the four fundamental physical forces, i.e., electromagnetic interaction, and strong and weak nuclear interactions. Fundamental particles are particles that cannot be decomposed because they do not have components (this is the traditional, synchronic meaning of "fundamental"), and they have three properties that are usually considered essential: mass, charge, and spin. Moreover, these particles are affected by decays involving their transformation into other particles, and these transformations, in Humphreys' view, are examples of diachronic emergence.

First, it should be noticed that the term "decay" may recall *radioactive* decay, namely the process that affects unstable atomic nuclei which spontaneously shed the particles that prevent them from being stable, emitting neutrons, protons, electrons, or other subatomic particles. In these cases, therefore, decay results from the release of one or more components of the atom, and this is possible because atoms have an internal structure and are composed of subatomic parts. In the case of particle decay, however, the same does not apply. A particle such as a muon has no substructure or constituent parts, yet decays into other particles such as electrons, electron neutrinos, or muon neutrinos. This decay cannot be understood as a decomposition, as in the case of atomic radioactivity, but must be seen

[5] The notion of strong emergence, which can be easily found in the literature (O'Connor, 1994; Bedau, 1997; Chalmers, 2006; Gillett, 2016), is a kind of ontological emergence implying the existence of novel, irreducible causal powers which allow for what is called "downward causation".

[6] See Kim (1999, p. 8): "What is being denied by emergentists is the theoretical predictability of [the emergent property] *E* on the basis of [the microstructural property] *M*: we may know all that can be known about *M* [...] but this knowledge does not suffice to yield a prediction of *E*".

[7] But also, inferential and conceptual, for obvious reasons.

as a genuine transformation of the muon into another fundamental particle characterised by different essential properties.

For Humphreys, particle decay is an instance of what he calls *transformational emergence*, namely a model of ontological and diachronic emergence that he describes as follows:

> Transformational emergence occurs when an individual *a* that is considered to be a fundamental element of a domain D transforms into a different kind of individual *a**, often but now always as a result of interactions with other elements of D, and thereby becomes a member of another domain D*. (2016, p. 60)

This model of emergence, therefore, involves the transformation of a fundamental entity into another fundamental entity and avoids classic criticism about causal overdetermination: in fact, the original properties do not causally compete with the emergent ones, given that the former no longer exists after their transformation into the latter.

Particle decay satisfies several criteria for emergence. First, what Humphreys calls (i) "precedence relation" (2016, p. 28): the emergent particle *diachronically depends* upon the previously existing particle. Emergent phenomena, in other words, "must result from something else" (*ibid.*, p. 27). Then, (ii) autonomy: the new fundamental particle is a *distinct* entity which does not synchronically depend upon the other particle to exist, so it is autonomous. Finally, (iii) novelty: the emergent particle has essential features that are *different* (i.e., novel) from those of the previously existing particle from which it emerged.

As a last remark, it should be noted that in Humphreys' framework, novelty is always relative to a domain. An entity is novel with respect to the domain D when it cannot be included in the closure conditions that define D, and these conditions can be logical, causal, or nomological (Humphreys, 2016, pp. 29 *et sqq.*). For instance, if the domain D is defined by the fact that certain physical laws apply (nomological closure conditions), those laws apply for all the entities belonging to D. If different laws apply for an entity E, then E cannot be included in D.

Domains, however, are not levels. They are less wide and general, and this allows for an emergent entity to be in a domain that is novel with respect to the domain of the entity from which it emerges without being at a different ontological level. This means that there may be emergent phenomena *within* the same level of the emergence base: physical phenomena emerging from other physical phenomena, for instance. For obvious reasons, the models involving this intra-level kind of emergence are called "flat".[8]

4. *Free will. An example of Strong emergence*

The second case of emergence that I suggest analysing is described by Jessica Wilson (2021). Like Humphreys, Wilson has devoted much energy and time to formulating an exhaustive taxonomy of emergent phenomena. Unlike Humphreys, however, she sets aside

[8] In addition to Humphreys', other flat models of emergence were developed by Guay and Sartenaer (2016) and Sartenaer (2018).

the epistemological cases of emergence (the "inferential" and "conceptual" ones) as well as the purely diachronic ones.[9] Wilson therefore focuses on ontological —or, as she calls it, "metaphysical"— emergence, and considers cotemporal forms of it, namely cases in which a natural entity is ontologically and causally autonomous despite being "cotemporally materially dependent on micro-configurations of fundamental physical entities" (2021, p. 6).

At the beginning of her book *Metaphysical Emergence* (2021), Wilson identifies two key questions: the first is "what is metaphysical emergence" and the second is "whether there actually is any metaphysical emergence" (2021, p. 7). To answer the first question, Wilson develops a taxonomy that acknowledges two forms of metaphysical emergence. The first one is "Strong emergence" and is characterised by the presence of (at least) one fundamentally novel causal power; the second one is "Weak emergence" and is characterised by the presence of a novel causal profile.

Briefly, for a phenomenon to be Strongly emergent, it must satisfy what Wilson defines the "New Power Condition", which states that "Token feature *S* has, on a given occasion, at least one token power not identical with any token power of the token feature *P* upon which *S* cotemporally materially depends, on that occasion" (2021, p. 51). In other terms, a higher-level natural feature *E* is Strongly metaphysically emergent if *E* has at least one fundamental power not possessed by the lower-level feature on which it synchronically depends.

As for Weak emergence, Wilson identifies another condition: the "Proper Subset of Powers Condition", which states that "Token feature *S* has, on a given occasion, a non-empty proper subset of the token powers of the token feature *P* on which *S* cotemporally materially depends, on that occasion" (2021, p. 71). In other words, the higher-level natural feature *E* is Weakly metaphysically emergent if *E* has just a proper subset of the powers possessed by the lower-level feature on which it synchronically depends. If *E* has this subset of powers, then it represents a case of Weak emergence, with no novel causal powers but a different (i.e., new) causal profile.

After drawing her taxonomy, which answers the first of the two questions asked at the beginning of her book, Wilson focuses on the second one, namely whether there are cases of emergence. She considers four possible candidates —complex systems, ordinary objects, consciousness, and free will— and concludes that while there are reasons to regard the first three as weakly emergent, free will seems to fulfil the New Power Condition. Free will, in short, exhibits a novel, fundamental causal power not possessed by the lower-level feature on which it depends, namely "the power to freely choose to φ" (2021, p. 266). The agent endowed with free will, in other terms, has a new power that transcends the nomological net of the physical. So, "freely choosing to φ" means that it is genuinely "up to the agent" whether to choose φ or not (2021, pp. 275 *et sqq*.).

In Wilson's framework, therefore, free will is Strongly emergent because of two essential features: (i) the cotemporal material dependence upon low-level features, and (ii) a novel causal power. In short, dependence and novelty are the criteria that define Wilson's model for Strong emergence.

[9] In fact, Wilson argues that there is no "need for a distinctively diachronic notion or relation of metaphysical emergence" and states that most accounts of diachronic emergence can be either subsumed under her cotemporal account or seen as instances of causation (Wilson, forthcoming).

This might seem similar to the case of particle decay, but it is not. While emergent particles are *diachronically* dependent upon previously existing particles, free will is *co-temporally* dependent upon the low-level entities composing its material substrate. This means that in the first case, the "emergence base" is not synchronically necessary for the maintenance of the emergent phenomenon, but in the second case it is. As for novelty, according to Humphreys it is always relative to a domain, so the novel features exhibited by the emergent particles are novel with respect to the previously existing particles, but not with respect to other domains or levels such as the physical. In Wilson's Strong emergence, by contrast, novelty is fundamental, and this means that Strong emergence is incompatible with physicalism, given that the emergent novel causal power is able to "produce effects entailing the violation, in particular, of Physical Causal Closure" (Wilson, 2021, p. 46).

5. *Division of labour in ant colonies. An example of scientific emergence*

The third example of emergence that I would like to examine cannot be traced back to just one author but has been described by many biologists and complexity scientists. In this paper, however, I follow Sandra Mitchell's considerations on the topic, which are particularly relevant from a philosophical point of view.

In complexity science, talk about emergent properties and behaviours is common, and one classic example is that of social insect colonies. While analogous examples can be found in bees, wasps, and termites, here I will focus specifically on ants. The emergent feature at issue is the division of labour, as this emergent behaviour is an example of what Mitchell calls "scientific" emergence.

Ants evolved from wasps in the Cretaceous, 140 million years ago. Biologists identified approximately 12.000 ant species, and places like the tropics still hide many species that are yet to be discovered. Ants are present in all continents except Antarctica, and their size, colour, diet, and behaviour vary in response to the different environments in which they live. Only a few of the known species have been adequately studied, so our knowledge about them is very limited. What we do know is that all species of ants share a significant feature: they live in colonies. Colonies can be of different dimensions: from little nests with a bunch of ants to super-colonies composed of sub-colonies and containing several millions of individuals. In every colony there is one, or more than one, reproductive female —the "queen"— and many sterile working ants that perform different tasks, such as hunting and searching for food (i.e., foraging), defending and maintaining the nest, taking care of the queen, the eggs and the larvae, and so on (Gordon, 2016).

Division of labour in ant colonies is interesting because the behaviour of individual ants is chaotic and unpredictable, but once together, ants manifest ordered group behaviours. How this happens is not completely clear. On the one hand, ants do not seem genetically "programmed" to perform particular tasks (Oster & Wilson, 1978; Trible & Kronauer, 2017) and even if some theories correlate size and task, only a few genera exhibit size variations (Gordon, 2010). On the other hand, tasks are not rigidly determined and can change in case of necessity, such as when the needs of the colony vary in response to envi-

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ronmental changes.[10] The behaviour of every single ant, therefore, depends on a complex relational structure involving each ant, its proximate nestmates, and the environment —intended in both its abiotic and biotic forms. What is surprising, however, is that from this "low-order" network of *local* interactions, sophisticated, "high-order" *global* behaviours emerge at the level of the colony, including, as we saw, an effective specialisation and a sophisticated division of labour.

As highlighted by Mitchell (2003, 2012), these features are produced by the local interactions of the ants and the relationships between them and the environment, with no external or internal organisational blueprint. Indeed, a complex system like a colony self-organises thanks to a series of positive and negative feedbacks that reinforce or hinder the behaviour of the components, generating the emergence of exceptionally ordered and stable group behaviours. Individual interactions, in short, create a high-order structure that allows the colony to achieve sophisticated goals such as fungi cultivation, or aphid farming. The high-order structure, moreover, becomes effective at the low-level through a sort of "downward causation" that may be conceived as a form of *constraining* determination. In Mitchell's terms, "system level properties constrain and direct the behavior of the components" (Mitchell, 2012, p. 182).

In the division of labour, Mitchell thus detects three features that, in her opinion, define emergence in both philosophy and science: novelty, unpredictability, and causal efficacy —in particular, downward causation (2012, p. 173). The division of labour is (i) *novel* because it is a global, ordered behaviour that appears at the level of the colony without taking place at the level of individual ants. It is (ii) *unpredictable* because it is generated by the local interactions of the individual ants, and these interactions are non-linear. Finally, it exhibits (iii) *causal efficacy* and *downward causation* in particular, because the large-scale structure has causal effects on the low-level components.

In addition to these features, Mitchell makes an important point. Group behaviours in social insects emerge from self-organised and complex *dynamics*, and this last feature —the (iv) dynamical nature of emergent behaviours— is of particular interest, for it defines *scientific* models of emergence as opposed to the static, synchronic models formulated by philosophers like Jaegwon Kim (Mitchell, 2012). What Mitchell calls "scientific emergence", therefore, is produced by *dynamical* processes that generate and maintain high-level emergent behaviours.

Mitchell's model of scientific emergence may recall some features and criteria already mentioned during the examination of Paul Humphreys' and Jessica Wilson's models but, again, the differences are significant.

While the dependence of emergent behaviour on a complex dynamic might recall dependence on certain material configurations —as in Wilson's work—, Mitchell emphasises the *dynamical* nature of this configuration. A synchronic view of the relationships between the low-level emergence base and the high-level emergent phenomenon cannot fully

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[10] For instance: "An animal steps on the nest, or rain seeps in, and nest repairs are needed. There is a windfall of food, or there is a shortage. The changing environment continually shifts the numbers of ants required to perform each task, to repair the nest or collect food" (Gordon, 2010, p. 24). Other variables influencing the so-called "allocation task", which is the process of assessing the right number of workers needed in a particular situation, include the size of the colony (Detrain & Deneubour, 2006) and the ants' age (Tripet & Nonacs, 2004).

explain the appearance and maintenance of the latter. At the same time, despite being a diachronic form of dependence, Mitchell's account is equally distant from Humphreys' precedence relation involving transformations and disappearances of the emergence base. Obviously, unlike particles, ants continue to exist after the appearance of the global emergent behaviour. Their existence, in other terms, is synchronous with the appearance and maintenance of their division of labour.[11]

6. Ontological and epistemological pluralism about emergence

Despite being commonly related to core features such as novelty, (partial) dependence, and causal efficacy (but also autonomy, irreducibility, and fundamentality), emergence can be defined in various ways. The reason for this heterogeneity seems twofold. On the one hand, different models can arise from the different interpretations of those general concepts —and this is the *epistemological* side of the issue. On the other hand, given the alleged presence of emergent phenomena across different levels of organisation and domains (e.g., subatomic, biological/social, psychological), emergence will be naturally related to different features —and this is the *ontological* side of the issue. Pluralism about emergence is therefore justified by the different theories that can be formulated to define emergence, as well as the intrinsic heterogeneity of emergent phenomena.

The three accounts of emergence analysed here clarify what I just stated. They provide at least two interpretations of novelty (relative novelty in Humphreys and fundamental novelty in Wilson) and three accounts of dependence (Humphreys' diachronic precedence relation, Wilson's cotemporal material constitution, and Mitchell's dependence upon dynamical complexity). Moreover —consistently with their meta-metaphysical assumptions— the authors focus on different phenomena that naturally present different features.

The three models analysed here are therefore only partially overlapping, and the root of these differences, as mentioned, is both ontological and epistemological. On the one hand, the models describe different phenomena, namely fundamental particles, mental properties, and group behaviours in social insects. On the other hand, the three authors have different understandings of the notions they use to formulate their models: they intend concepts such as novelty or dependence (but the same can be said about causal efficacy) in different ways, identify different references for them in the world, and sometimes do not agree on what is emergent and what is not. For instance, Wilson argues that most accounts of diachronic emergence can be either subsumed under a cotemporal account or be merely seen as instances of causation. One of the diachronic accounts of emergence she contested is precisely Humphreys' transformational account, which in Wilson's opinion should be seen as a case of intra-level causation, being therefore "irrelevant for purposes of characterizing metaphysical emergence understood as accommodating leveled structure" (forthcoming). Wilson's reluctance to admit this phenomenon among genuine cases

[11] Other differences between Wilson's model and Mitchell's can be highlighted, particularly in relation to the stricter framework employed by Wilson compared to Humphreys. In Mitchell's model, novelty is not as fundamental as it is in Wilson's, and causal efficacy is admitted without any need for novel causal powers. Also, in Wilson's framework, constraining relationships may be considered too weak to guarantee genuine causal efficacy and autonomy.

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of emergence, however, depends on her theoretical assumptions, namely the fact that, according to her, not all types of dependence are suitable for emergence. Moreover, Wilson focuses on entities belonging to special sciences, namely macro-objects composed of lower-level parts and suggesting a levelled structure of reality, while Humphreys' case studies involve fundamental entities and no necessary intra-level relationships.

The heterogeneity in the description and modelling of emergence, however, does not end here. The properties analysed so far —novelty, dependence, causal efficacy— are *ontological* features of the systems in which emergence appears, and I focused on them because they are usually considered particularly relevant. Other properties are commonly recognised as typical of emergence, though, and these properties are *epistemic*. As highlighted by Humphreys (2016), for instance, one feature characterising emergent phenomena is unpredictability: the nature and evolution of emergent phenomena cannot be deductively predicted starting from the knowledge of their low-level components. Indeed, this is a classic criterion for emergence. Writing about water in *A System of Logic*, for instance, John Stuart Mill stated that "[...] no experimentation on oxygen and hydrogen separately, no knowledge of their laws, could have enabled us deductively to infer that they would produce water" (1843, p. 255). And the same can be found in George Henry Lewes' *Problems of Life and Mind*: "Who, before experiment, could discern nitric acid in nitrogen and oxygen? Who could foresee that gold would be changed into a chloride if plunged into a mixture of two liquids (hydrochloric and nitric acid), in either of which separately it would remain unchanged?" (1875, p. 414). As well as with dependence, autonomy, and causal efficacy, there are variants and nuances of deductive unpredictability as well. The epistemic irreducibility of emergent phenomena, for instance, has been defined through the concepts of predictability through simulation (Bedau, 1997), incompressibility (Bedau, 2011/2013), surprise (Chalmers, 2006), conceptual novelty (Humphreys, 2016), or computational intractability (Wuppuluri in Wuppuluri & Stewart, 2022).

Now, as mentioned in §1, this massive variety of case studies, core features, and criteria for emergence can be seen as a problem. Discussing this topic, for instance, Jessica Wilson states that "though in general a thousand flowers may fruitfully bloom, this much diversity is unhelpful as regards answering the first key question, concerning the nature and varieties of specifically metaphysical emergence" (2021, p. 15). For Wilson, answering this question is a difficult task because of the different interpretations of dependence and autonomy, giving rise to "a bewildering variety" (Wilson 2021, p. 13) of accounts of emergence. Her reaction to this challenging situation is that of proposing the two general schemas described in §4, to which all other models of emergence, in her opinion, can be adequately reduced. Her work is a careful analysis of the internal coherence of a certain idea of emergence and a detailed review of some cases of alleged emergent phenomena reread through her lens.

Now, what I wish to argue is that so much diversity may actually hold significance, so rather than reducing it to a couple of universal schemes, it should be analysed as it is. The pluralist stance about emergence I propose here stems from the idea that this diversity might be a sign of the complexity of nature, which naturally results in complex descriptions and explanations. Given this intrinsic complexity, in other terms, the plurality of the conceptual frameworks for emergence might correspond to the possibility of approaching nature from different perspectives, rather than missing *the* right access point.

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Normally, the concept of emergence refers to circumstances in which the organisation of certain entities in more or less complex configurations and dynamics leads to the appearance of novel, unexpected properties. However, the type of entities in question and the ways in which these entities can structure themselves are not univocal. Subatomic particles, for instance, behave differently from cells or biological organisms, besides having different individual properties. It is therefore natural for a concept with such a vast scope not to be monolithic and rather reflect the ontological richness of entities and relationships to which it refers.

In other words, it would be surprising if highly different phenomena such as those usually intended as emergent always manifested the same ontological features and could be always modelled in the same conceptual frameworks. Except by using extremely general —and therefore poorly detailed— models, this is not possible, because those phenomena belong to different ontological domains that are investigated by different sciences, grounded in different kinds of knowledge, methodologies, and practices. In conclusion, as stated by Sandra Mitchell, "our philosophical understanding of concepts (like emergence) should track not just logical consistency, but also empirical adequacy" (2012, p. 181) and the latter suggests a plurality of ways in which a phenomenon can be emergent.

7. Conclusions. Towards an open cluster theory of emergence

To sum up, in the last few decades, the idea of emergence has been employed to describe several phenomena in different philosophical and scientific frameworks, but there is no consensus in the scientific community on its exact meaning and scope. This circumstance may suggest a lack of conceptual clarity, but can also be intended as a sign of the complexity that is intrinsic to both nature and our knowledge of it.

An examination of the literature about emergence —of which I provided a small example here— reveals the existence of several models that are both logically accurate in analytically defining the concept of emergence and empirically adequate in applying the concept to the description of real-world cases of emergence. This may suggest that different natural structures and processes give rise to different emergent phenomena and that, consequently, different accounts can be formulated to access and model them. To capture the nature of emergence, a heterogeneous set of properties, concepts, and models might be needed, and this is where the concept of *open cluster* comes in.

The notion of cluster has been central to the debate on the meaning and reference of names and has been employed by authors such as Ludwig Wittgenstein (1953), Peter Strawson (2002) and John Searle (1958). In the 1990s, Richard Boyd applied the notion of clusters to the problem of natural kinds in biology and formulated the so-called Homeostatic Property Cluster (HPC) theory (1991). My suggestion is that it might be reasonable to approach emergence in a similar way.[12]

Boyd's theory holds that certain natural kinds, given their complexity and the imperfection of the sciences that study them, cannot be defined by any set of necessary and suf-

[12] This same suggestion is mentioned —but not further developed, to my knowledge— by Mark Bedau as well in the introduction of Bedau & Humphreys, 2008.

ficient conditions but rather by a "'homeostatically' sustained clustering" (1999, p. 143) of properties and relations which *constantly* but *contingently* co-occur in nature.[13] There are therefore biological kinds that do not instantiate all the properties usually clustered, but just a subset of them, and this is normal given the complexity of biological phenomena and the "imperfection" of our scientific knowledge. I believe the same can be said about emergent phenomena. The ontological properties defining them (novelty, autonomy, irreducibility, causal efficacy and so on) can be steadily recognised, but in a contextual manner that makes it impossible to identify a stable pattern across all levels of organisation and size. Rather than identifying necessary and sufficient conditions for emergence, therefore, it might be better to individuate a cluster of properties that can guide us in the study of emergent phenomena, though none of these properties is always sufficient or always necessary.

This cluster, moreover, should be open for at least two reasons. The first one, which is epistemological, is that our knowledge about reality is constantly increasing and novel concepts might be formulated in the future to describe and identify old or newly discovered emergent phenomena. The second one, which is ontological, is that emergence represents one of the ways in which matter organises itself, and this organisation is subject to natural evolution, so it cannot be ruled out that new forms of biological organisation will appear in the future, just as new forms have appeared so far in the course of history.

In conclusion, the cluster of properties and theories defining emergence should be left open for several reasons, and this is perhaps the only way to recognise and respect the heterogeneity that characterises emergence —a heterogeneity that stems from the complexity of reality and reflects both its ontological structure and the plurality of epistemologies that this structure enables.

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[13] It should be noted that the analogy between Boyd's theory and my proposal to address emergence employing the notion of cluster is limited in scope. In Boyd's view, for instance, what holds the cluster together —i.e., what maintains the clustering or "sociability" (Chakravartty, 2007) of the clustered properties— are homeostatic *causal* mechanisms. In the case of emergence, it may sometimes be the same and sometimes not. As suggested by Slater (2015), a more flexible and general way to justify the stability of the cluster might be better than just focusing on causal mechanisms. However, this is a complex issue that will be addressed on a different occasion.

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