On contextual and ontological aspects of emergence and reduction

[Draft 11.7.19]

Esteban Céspedes

Valparaíso University, Department of Philosophy /
Valparaíso Complex Systems Institute
esteban.cespedes@uv.cl

Abstract

Although the interest about emergence has grown during the last years, there does not seem to be consensus on whether it is a non-trivial, interesting notion and whether the concept of reduction is relevant to its characterization. Another key issue is whether emergence should be understood as an epistemic notion or if there is a plausible ontological concept of emergence. The aim of this work is to propose an epistemic notion of contextual emergence on the basis of which one may tackle those issues.

Keywords: contextual emergence, ontological emergence, downward causation, consciousness, novelty

1 Background

According to a classic notion, emergent properties are properties of a system that depend on, but are irreducible to the system's constituent elements (cf. Kim, 1999; 2006). Charles Dunbar Broad (1925), one of the British emergentists, characterized emergent properties in a way that can be formulated as follows (Beckermann, 1992, p. 17):

> 1.1 *Emergent property*. A property F of a system S, made up of the constituents $C_1, \ldots, C_n$ standing in a certain relation R to each other, is emergent if and only if (a) there is a law to the effect that all systems with the same make-up have F, and (b) F nonetheless cannot, even in theory, be deduced from the most complete knowledge of the properties of the components $C_1, \ldots, C_n$ in isolation or in systems with a different make-up.

Condition (a) states that there must be a dependence between an emergent property and the constituents of the system in which it arises. Emergent properties occur in all systems in which certain kinds of components are organized in a certain way. They depend on those kinds of components and on their organization. The latter is crucial, as condition (b) establishes. One cannot deduce the instantiation of an emergent property without considering the particular organization on which it depends. Thus, emergent properties are irreducible in this sense.

One could define emergence in terms of this classical notion, understanding it as the process in which emergent properties are formed in a system. Although this definition seems plausible, it is not very informative if we are interested in the diachronic aspect of emergence, that is, in the *arising* of emergent properties. Even if emergence can be related to irreducibility and complexity, it is not clear how we should understand it as a relation[1], i.e. how we should understand the fact that some properties appear from the interactions of a system's constituents.

Recent accounts usually associate emergence with the complexity of a system, i.e. with how numerous its parts and their interactions are (cf. Holland, 2014). Thus, emergent properties are properties that arise in a system when the system's complexity increases considerably (cf. El-Hani & Pereira, 2000; Fuentes, 2014). Understanding emergence in terms of the increase of complexity may account for the procedural, non-static aspect of this relation. But complexity alone does not seem to express the fact that emergent properties are determined by and irreducible to the system's constituents.

Considering certain notions of reduction, such as identity and functional reduction, the irreducibility of emergent states implies that their causal

[1] I will assume that emergence is a general relation. This does not mean that there is only one kind of emergence. As shown, different notions of emergence can be derived from a broad one. Also, such a general notion will be defined as a set of relations.

efficacy is beyond the causal efficacy of the constituents underlying the system in which they arise. If emergent states were strictly identical to some set constituents, their causal powers would also be identical to the causal powers of the constituents. The same holds for functional reduction, since a state *A* is functionally reduced to a state *B* just in case *A* plays the same causal role as *B*. Thus, the irreducibility of emergent states could allow us to accept that they may cause states that their constituent parts can't. They could be considered as causes of other emergent states, as in cases where an ecological state causes other ecological states (*horizontal causation*). And even more interestingly, they could be causes of lower-level states, such as when ecological states influence the behavior of an ecosystem's members. These are cases of *downward causation*.

But downward causation is not unproblematic. Consider this version of the well-known exclusion argument, which can be applied against it (cf. Kim, 2005, p. 19): Let us assume that any event that has a cause, has a sufficient physical cause, and that sufficient physical causes exclude other kinds of causes. Assume further that there are no genuine cases of overdetermination, i.e. if an event has a sufficient cause *c*, then no event distinct from *c* can also be considered a cause of that event. Now, if any macroscopic, emergent state *e* is able to cause another macroscopic state *e′*, it must also be able to influence the microscopic, physical basis of *e′*. That is, downward causation should be possible. But this contradicts the first two assumptions: Since the physical basis of *e′* has, as assumed, a sufficient physical cause, the causal capacity of *e* must be excluded from the picture. Therefore, downward causation does not seem to be possible.

Mark Bedau (1997) distinguishes *weak emergence* from *strong emergence* in order to tackle the problem of the causal efficacy of emergent states. According to his account, an emergent state is weakly emergent just in case its description can be derived from descriptions of microstates, but only by simulation. Roughly, a simulation is a representation of iterating, causal interactions between the micro elements of a system. On this basis, certain configurations observed in simulation processes can be considered as emergent states and have causal powers that are distinct from the causal powers of the microstates underlying them. Strong emergent states, by contrast, are the ones that are not reducible at all. The question is, following this distinction, "What can we call a strongly emergent property"? According to David Chalmers (2006), consciousness is a clear example of a strongly emergent state. A state is conscious if there is something it is like to be in that state.

Also contrasting with the traditionally assumed irreducibility of emergent states, Jeremy Butterfield (2011) shows that emergence and reduction are compatible, even if we assume a strong notion of reduction, such as Nagelian reduction (Nagel, 1961). Butterfield understands emergence as novel and robust behavior and, according to his account, whether a given emergent behavior can be reduced depends on the values of certain parameters, such as a system's degrees freedom or the number of iterations associated with the system in some definitional process.

Not everyone thinks that the notion of reduction is necessary for characterizing emergence. Karen Crowther (2015) tackles the topic focusing on the philosophy of physics and argues, on the basis of effective field theory, that the notion of reduction is irrelevant for defining emergence. According to effective field theory, physical theories are hierarchically ordered depending on energy scale. On this basis, emergent behavior is understood as novel and autonomous behavior. Roughly, according to Crowther, novelty expresses that the relevant interactions involved in high-level theories are not present in low-level theories, while autonomy (actually, *quasi-autonomy*) means that high-level theories are independent of low-level details[2].

So, traditionally, the notion of reduction has been relevant for the understanding of emergence and even if not every analysis of emergence is based on reduction in some way or another, the most crucial issues regarding emergent states are related to their presumed irreducibility. Considering the perspectives just reviewed, we may ask six crucial questions that any clear account on emergence should tackle:

a) How are emergent states dependent and, at the same time, irreducible to a system's constituents?
b) What is the role of complexity with regard to emergence?
c) How is downward causation possible?
d) In which sense are states of consciousness emergent?
e) Is reduction compatible with emergence?
f) Is the notion of reduction even relevant for characterizing emergence?

These questions will not be answered by giving an analysis of each one of the topics they represent, but they will guide the main discussions of the following sections.

2 Contextual Emergence and the consistency challenge

Some of the issues mentioned in the previous section are part of what Olivier Sartenaer (2016) calls the *consistency challenge*. This problem can be stated as follows:

2.1 *The consistency challenge*. It is difficult to understand how emergent states are determined by the constituents of a given system and are, at the

[2] While the accounts of Crowther and Butterfield are focused on physical emergence, I am concerned here with the notion of emergence in its general sense and with how it may be applied in a diverse class of cases. Of course, it is crucial to study in which particular cases or fields is reduction relevant and in which cases not, but I will not pursue this task here.

same time, unexplainable, autonomous and irreducible.

This is a serious issue and must be considered if we want to explain in which sense emergent states are irreducible and explanatorily relevant. In what follows, I will propose a definition of the notion of emergence that not only may tackle the consistency challenge, but is actually directly motivated by it. According to the proposal, emergent states are reducible and irreducible at the same time. And they must be so. Of course, this rough characterization is a clear contradiction and has to be reformulated in order to be included in a coherent account.

An appropriate way to dissolve apparent inconsistencies is to consider from different perspectives the different propositions that seem to be mutually inconsistent. Such perspectives can be called *contexts*.

Let a context be a set containing descriptive, normative and phenomenal information, which determines, in the form of a background, the truth value or correctness of certain propositions. Thus, contexts may include norms, interests, laws, descriptions and non-descriptive expressions about experiences[3]. Here is an example that may illustrate the role played by a context. The proposition "The fact that Susan took a child's surfboard without permission was wrong" seems to be true, given commonly accepted moral norms. These moral norms are part of a context that determines the truth-value of the considered proposition. Now, suppose that we learn that Susan took the surfboard to save a drowning person. Adding this new information to the context and considering the value of saving a life, the proposition seems to be false. One of my aims will be to show that, regarding emergence, propositions about reducibility can be plausibly understood as context-dependent in a similar way and that this will be helpful to answer the consistency challenge. Before showing how this can be done, let us focus on further aspects of the notion of a context assumed here.

Contexts can be ordered by a relation of aboutness. A context K is of a higher level than a context K' if K involves information about expressions that are part of K' but K' does not involve information about K[4]. For instance, a context focused on organizing board games may involve information about a context focused on chess, but the latter would probably not involve

[3] Although it is associated with semantic aspects, this is not exactly the semantic notion of context, which is usually understood as a set of parameters. John Perry (2001) makes a distinction between two types of semantic contexts. Narrow contexts include only a speaker, a place and a time. Wide contexts may include additional parameters, such as intentions and sets of conditions. The notion of context characterized in this work corresponds to the one of a wide context. However, it is not only associated with semantic and pragmatic features, but also with scientific, theoretic and perceptual ones.
[4] Contexts may contain linguistic expressions that can be interpreted from the perspective of other contexts. Thus, they also involve information or propositions. Although the information contained in a context can be fixed within the context itself, we do not have to focus always on those internal interpretations.

information about the former[5]. In this sense, the context focused on organizing games is informationally higher in the hierarchy or is more general than the context focused on chess. We may say then that the second context is accessible from the first, calling the former a *subcontext*. Contexts also have an internal relevance structure on the basis of which their information is ordered and can be distinguished accordingly. Let *descriptive contexts* be contexts in which descriptions are especially relevant, *normative contexts* be contexts that are mainly about norms and *observational contexts* be contexts that are mainly focused on observations. Different kinds of contexts may be interrelated in different ways. For instance, an observational context may be supported by some descriptive context that provides explanations for some observations or it may be guided by some normative context that indicates what to observe or what to avoid doing while observing something.

Wth this general idea of a context we can define emergence—in particular, the notion of an emergent state—as follows:

> 2.2 *Contextual emergence*. From the perspective of context *K*, a set of states *E* is emergent from a set of states *B* just in case there are three contexts, K_1, K_2 and K_3, accessible from *K*, such that the following conditions are met.
> 2.2.1 According to K_1, *E* is reducible to *B*.
> 2.2.2 According to K_2, *E* is irreducible to *B*.
> 2.2.3 According to K_3, *E* involves novel properties with regard to the properties found in *B*, which are correlated with an abrupt change of complexity of *B*, according to *K*.

This definition is focused on emergence as a relation and on the notion of an emergent state[6], but it does not say anything explicitly about the notions of emergent phenomenon and emergent property, which are common within the literature about this topic. These can be seen as derivative notions based on the definition just given:

> 2.3 *Emergent phenomenon*. Let *E* be an emergent state according to some context *K* and *Ko* an observational context, accessible from *K*, in which the novel properties of *E* are observed. The phenomenon corresponding to

[5] Of course, information about chess will contain information about board games, because chess is a board game. But it does not have to contain information about how to organize board games.

[6] In general, I will neither assume distinctions between states and descriptions of states nor between properties and predicates. Since the notion of context considered here is fundamentally theoretical, to say something about a state, from the perspective of a context, usually means to say something about a description and to say something about a property, according to a context, means to say something about a predicate. This assumption holds unless I focus explicitly on non-descriptive items, such as phenomenal or normative states.

that observation is an emergent phenomenon, according to *K*.

2.4 *Emergent property*. Let *E* be an emergent state according to some context *K* and *K'* a context, accessible from *K*, that involves the novel properties of *E*. In *K*, these are emergent properties.

Condition 2.2.1 indicates reducibility, i.e. that reduction should only be possible, not that it must be achieved. Thus, for instance, we may consider an emerging flock of birds as reducible to the states and motions of the singular birds that constitute the group, even if we are not actually reducing the emerging behavior in that context. Contextual emergence must not be constrained to any notion of reduction in particular, although functional reduction is especially relevant because it allows us to tackle the problem regarding the causal efficacy of emergent states. As mentioned before, functional reduction can be characterized in the following way:

2.5 *Functional reduction*. A state *E* is functionally reduced to another state *B* if and only if these conditions are satisfied:
2.5.1 Any state that causes *E* also causes *B*.
2.5.2 Any state that is caused by *E* is also caused by *B*.

In other words, a state is functionally reduced to another when the causal profile of the first is included in the causal profile of the second (cf. Shoemaker, 2007). Note that functional reduction does not imply that one of the states is more fundamental than the other. It is not an antisymmetric relation; it is possible that *A* is reducible to *B* and that *B* is reducible to *A*. Of course, it may be that *E* is reduced to *B* when *B* is more fundamental. And the manifestation of this would be that some states that are causes or effects of *B* are not part of the causal profile of *E*.

I will assume that, for functional reduction, any instantiation of a property (such as events, states or facts) can be taken as a relatum of the causal relation and any notion of causation based on difference-making (cf. Ney 2009) is applicable to the account of emergence proposed here. A physicalist notion of causation may also be appropriate. Take, for instance, Phil Dowe's (2000) account of physical causation, according to which, two events are causally related if they are connected by the transmission of some conserved quantity. It is not problematic to accept that interactions occurring between constituents of a system may interact causally in this sense. However, there is the challenge of describing the higher-level states of the system in those terms.

Consider, for example, drought periods, which can be seen as states of an ecosystem that arise from different interactions between the system's members and other conditions. These could be described involving quantities such as temperature and humidity. A first issue regarding functional reduction on the basis of physical causation consists in the fact that, in order to treat those quantities as conserved quantities, one must assume that there is some closed system in which they are assigned. Clearly, this cannot be the ecosystem to which we attribute the drought in the first place. If that assumption is not made, a broader system must be chosen for the purposes of reduction. This issue should not be a problem for difference-making accounts of causation. If both the drought and *B*, a given low-level state of the system, make differences in some other state and if some previous state influences both, the drought and *B*, then they share a causal profile. In this sense, the drought is reducible to the low-level state regardless of whether the kinds of properties involved in the description of the latter are strictly physical or not.

A second issue would consist in expressing the effects of the drought period, such as the migration of some species, in terms of conserved quantities. This could be done by constructing a statistical model of the species' population and treating each individual as a unit of the quantity that measures that species' population. This issue is neither a problem for difference-making accounts of causation. One may assume a single description for the migration and determine that both the drought as a high-level process and the corresponding low-level state make differences on the migration process. It is possible, however, that both do not produce the same amount of difference in the considered effect. Anyway, ceteris paribus, if the drought had not occurred, the migration would not have occurred. Now, a description of the low-level state corresponding to the drought must be more specific than a description of the drought. This means that low-level variations may have implied specific variations in the migration process, like its duration, but not necessarily its non-occurrence.

A third issue is the fact that, after producing a physical characterization of the drought period, it is no longer plausible to say that the causal profile of the drought is included in the causal profile of its physical description. It is rather a case of methodological replacement of a state's description. This is not a problem for difference-making accounts of causation, since the description of low-level states must neither be considered as a re-description of, nor as a replacement of the drought.

Despite the difficulties just mentioned, I think that functional reduction is possible under appropriate assumptions, i.e. under appropriate contexts. Since contexts are here defined not only in terms of the descriptions they contain, but also on the basis of their normative aspects, the plausibility of functional reduction will depend on pragmatic and methodological assumptions.

Let us now turn to condition 2.2.2. It establishes that emergent states are irreducible from the perspective of a certain relevant context, which is distinct from the reduction context. Irreducibility may hold because *E* cannot be functionally reduced to *B*, as when, for instance, we cannot reduce an economic crisis to the set of descriptions involving economic agents. An economic crisis may have effects on political decisions, but the latter can hardly be taken as effects of just low-level economic behavior. Irreducibility may also hold when *B* has not a suited interpretation, which can occur in the observation of a figure constituted by materials that are unknown to the observer.

As in the case of reduction, whether a state is irreducible will not only depend on the descriptive aspects of a given context, but also on its normative aspects, usually associated with the aims of inquiry and with interests of different sorts.

It should be simple now to understand in which sense the contextualist strategy proposed here allows us to tackle the consistency challenge. How can emergent states be determined by the constituents of the system in which they arise and, at the same time, be irreducible to them? The key is to read “at the same time” as “at the same time, but in a different context”. Thus, emergent states are determined by the system’s constituents and, at the same time, but in a different context, irreducible to them.

As noted earlier, the account of contextual emergence proposed here is not restricted to any notion of reduction in particular. A particular focus on functional reduction was made because it is understood in terms of causal roles, which is especially important if we want to tackle the problem of downward causation. Now, if there is any restriction that may be relevantly considered at this point, it is the one based on the distinction between ontological and representational, i.e. epistemological reduction (cf. van Gulick 2001). Here are four main notions of ontological reduction:

2.6 *Elimination*. A state *A* is reduced to a state *B* just in case *A* is ontologically nothing but *B*, which implies that *A* can be replaced by *B*.

2.7 *Identity*. *A* is reduced to *B* just in case *A* is identical with *B*.

2.8 *Composition*. *A* is reduced to *B* just in case *A* is entirely composed by *B*.

2.9 *Supervenience*. *A* is reduced to *B* just in case there cannot be differences regarding *A* without differences regarding *B*.

According to Robert van Gulick (2001, p. 3), an ontological notion of reduction stands for a relation that links items in the world, as opposed to representational notions, which are about relations between representational items. Now, four important examples of representational reduction are the following:

2.10 *Replacement.* A description (proposition or representational system) *A* is reduced to a description *B* just in case *A* is theoretically replaced by *B*.

2.11 *Derivation*. A description *A* is reduced to a description *B* just in case

A can be derived from *B*, given the appropriate set of laws and conditions.

2.13 *Expressive equivalence*. A description *A* is reduced to a description *B* just in case every fact that can be represented by *A* can also be represented by *B*.

2.14 *Teleo-pragmatic equivalence*. A description *A* is reduced to a description *B* just in case every fact that can be represented by an agent *S*, using *A* within a social and physical context *C*, according to a theory T_1, can also be represented by *S*, using *B* within *C*, according to T_2. (cf. van Gulick 2001, p. 14)

The proposal of reduction as teleo-pragmatic equivalence put forward by van Gulick is a contextualist one, like the account of emergence explored in the present work[7]. On this basis, teleo-pragmatic equivalence seems to be a suited notion to be included within a specification of the conditions for emergence. Assuming that theories are a kind of epistemic context, we would say that the description of a system's emergent state represents, according to a certain context, the same state as the descriptions of the system's constituents, but, according to another context, it does not. Again, this is how emergent states can be considered as reducible and, at the same time, irreducible to the parts of the system from which they arise.

Of course, to think that reduction as teleo-pragmatic equivalence is particularly appropriate to support contextual emergence does not mean that other notions of epistemic reduction should be ignored. We could characterize a notion of emergence based on reduction as replacement, as well as a notion based on reduction as derivation. Both can be special cases of contextual emergence, if the characterizations involve the proposed conditions. The theoretical strength of each special case may vary depending on the notion of reduction that one assumes. Thus, emergence based on replacement would probably be a stronger and more demanding notion than emergence based on expressive equivalence.

Furthermore, we can, in principle, include notions of ontological reduction in specifications of contextual emergence. All depends, in a certain sense, on our ideas about how independent ontology is from epistemology. This issue will be considered later, in *section 5*.

Let us focus on condition 2.2.3. In order to grasp the main point expressed by it, we need to characterize the notion of novelty. This can be done as follows:

2.15 *Novelty*. According to a context *K*, *P* is a novel property just in case,

[7] A fundamental difference between both accounts is the fact that, according to the version of the teleo-pragmatic account here characterized, the context could (at least in principle) be referring to something objective, to facts of the world, while I treat contexts as epistemic items.

in *K*, there are two sets of states, *F* and *G*, such that *F* is considered before *G* and *P* is not involved in *F* but in *G*.

This is a general notion of novelty. More specific are the notions of synchronic novelty and diachronic novelty. Cases in which *F* and *G* are simultaneous are cases of synchronic novelty and cases in which *F* and *G* occur at different times are cases of diachronic novelty[8]. Note the difference between saying that, according to *K*, *F* is *considered* before *G* and saying that, according to *K*, *F occurs* before *G*. Both kinds of novelty are crucial to understand emergence. Consider, for instance, the patterns formed by a flock of birds. These patterns emerge from the interactions between the birds, which are the constituent parts of the flock. On the one hand, synchronic novelty is a characteristic of the fact that the patterns and figures formed are properties of the flock as a system, not of its constituents. On the other hand, diachronic novelty is also present if we consider the different changes of the flock patterns that can be observed, including changes from states that do not involve any relevant formation at all. Observation is here broadly understood. One can observe patterns formed by a flock of birds or regularities in a data set.

Complexity is also important in condition 2.2.3. I will only consider a general, comparative notion. Given two systems, *s* and *s′*, if *s* involves a greater number of constituents, more types of constituents, a greater number of interactions and more types of interactions than *s′*, then *s* is more complex than *s′*. Note that a high number of parts and interactions is not enough for complexity. A huge bunch of stuff may not be complex. But a big group of different entities interacting in different ways, such as an ecosystem, may be seen as a complex system.

An increase or a decrease of complexity, according to some reduction context, may be associated with the observation of a novel property, but this does not mean that the presence of complex behavior is a sufficient condition for emergence[9]. However, complexity needs to be included somehow as a necessary condition for emergence. A first reason is that whether some property is emergent does not simply depend on how new it is observed. If it was so, noticing a crack on a wall for the first time would be enough to call it an emergent state. Of course, according to certain sets of conditions, a crack on the wall may be taken as an emergent property, but the novelty of this property should be correlated with the increasing complexity of the system seen from a general context and should not simply depend on the observational context. This means that complexity contributes to a richer

[8] The account of Karen Crowther (2015) defines emergence in terms of synchronic novelty. A different analysis is offered by Alexandre Guay and Olivier Sartenaer (2016), who analyze emergence on the basis of diachronic novelty.

[9] As established in condition 2.2.3, there must be an abrupt change of complexity. How abrupt should it be? Well, it must be sufficiently abrupt to cause novelty, i.e. the appearance of a new property.

understanding of diachronic novelty. A mere change of states in a system is not enough for emergence.

A second reason to include complexity in the analysis of emergence is the fact that it introduces a further asymmetry besides the temporal asymmetry already associated with diachronic novelty. While diachronic novelty is a feature that may depend only on the appearance of a system's high-level properties, changes in complexity may depend just on the system's low-level interactions[10]. The key point about condition 2.2.3 is that high-level novelty should be related to low-level changes of complexity. Of course, low-level changes of this kind also imply novelty, according to the definition given above.

The notion of emergence just proposed is non-trivial in the sense that there are clear conditions according to which a given property is not emergent. It allows for the detection of emergence in everyday situations and also in more rigorous contexts, as should be clear later. In the following section, three cases of emergence will be described considering the definition proposed in this work.

3 Examples of emergence

The cases of emergence that will be considered in this section correspond to three different areas. The first is a case from thermodynamics, the second one is a case from biology and the third is from the philosophy of mind. For each example, I will simply offer one possible way of treating it as a case of emergence. Here is the first case:

> 3.1 *Phase transition*. Suppose that the high-level state of a system changes from a liquid state *l* to a gaseous state, *g*. The system is constituted by a huge number of interacting molecules. We may want to say that state *g* emerges from those constituents.

Let t and t' be two periods of time, such that t' is later than t. Let K be the context in which the following emergence claim is being assessed: State $g_{t'}$ (g at t') is emergent from the molecular micro-level state m_t. Let K_1, K_2 and K_3 be subcontexts of K. The emergence claim is true if and only if the following conditions hold:

3.1.1 *Contextual reducibility*. According to K_1, the state $g_{t'}$ (g at t') can be

[10] Consider, for instance, algorithmic complexity, which is defined in terms of the length of the shortest binary description of the system in question (cf. Kolmogorov 1965; Chaitin 1969). Essentially, it's all about the parts. However, there are other measures of complexity, based on the description of regularities and thus involving a higher order characterization (cf. Gell-Mann & Lloyd 2003).

reduced to the molecular state $m_{t'}$, given certain laws, conditions and reformulations.

In the case of contextual reducibility, we can use the notion of reduction as theoretical replacement. Such a replacement might be justified by observed correlations between $g_{t'}$ and $m_{t'}$. In this case, reduction might be acceptable even if there is synchronic novelty between $g_{t'}$ and $m_{t'}$.

3.1.2 *Contextual irreducibility*. According to K_2, $g_{t'}$ cannot be reduced to $m_{t'}$.

This might be the case if there is not enough information within K_2 to establish relevant correlations between $g_{t'}$ and $m_{t'}$. Another possibility is that $g_{t'}$ is considered as irreducible because another notion of reduction is the relevant one within K_2. For instance, it may be that, according to a notion of reduction as derivation, $g_{t'}$ cannot be reduced to $m_{t'}$.

3.1.3 *Novelty and complexity*. According to K_3, $g_{t'}$ involves properties that are neither involved in m_t nor in $m_{t'}$ (synchronic and diachronic novelty)[11]. Also, m_t and $m_{t'}$ differ considerably regarding their complexity.

Following the example of a phase transition, we could think of the forms of a gas cloud or its humidity as properties that are only part of $g_{t'}$. These are emergent features of the system. There is also a considerable change of complexity between m_t and $m_{t'}$, correlated with the observation of those relevant properties that are only present in $m_{t'}$. The complexity of the system at the low-level while being in a transition from a liquid to a gaseous state is higher than its complexity while just being in a liquid state.

Let us now consider a case from biology. An interesting feature of some species of bacteria, such as *Pseudomonas aeruginosa*, consists in the self-organization of colonies in certain ways that allow the colonization of higher organisms. This ability is a high-level, collective property that arises only when a given threshold of cell concentration is exceeded (cf. Funqua, Parsek & Greenberg, 2001; Luisi, 2006), permitting an increase of intercellular signaling based on chemical interactions. This is a case of emergence that can be described in the following way:

3.2 *Bacteria*. Consider a system constituted by individuals of the species Pseudomonas aeruginosa. Let c be a state of that system in which the group has the ability of colonizing higher organisms and t' be the time in which the system acquired that ability, such that $c_{t'}$ symbolizes the system having that ability at that point. Let b_t describe some lower-level state of the

[11] Depending on whether we focus on synchronic or diachronic novelty, we may define synchronic or diachronic emergence.

system, in which the cell concentration is increasing, and $b_{t'}$ a state of the system in which the cell concentration is considerably higher.

The emergence claim that we would like to evaluate is this one: According to K, state $c_{t'}$ is emergent from b_t. If this is true, we have to be sure that the required conditions hold, considering K_1, K_2 and K_3, which are subcontexts of K:

3.2.1 *Contextual reduction*. According to K_1, $c_{t'}$ can be reduced to $b_{t'}$.

Here, we may think of supervenience. Ceteris paribus, changes with regard to the system's ability to colonize higher organisms imply changes in the system's cell density.

3.2.2 *Contextual irreducibility*. According to K_2, $c_{t'}$ cannot be reduced to $b_{t'}$.

Let us follow van Gulick's (2001) notion of teleo-pragmatic equivalence, assuming that his notion of context can be captured by the epistemic notion of context involved in the present proposal. A description of $c_{t'}$ can be reduced to a description of $b_{t'}$ just in case every fact that can be represented by an agent S, using $c_{t'}$ within K_2, according to a theory T_1, can also be represented by S, using $b_{t'}$ within K_2, according to T_2. This does not seem to be true regarding the case considered here. We may, on the basis of the collective ability to colonize other organisms, represent potential interactions between a given population of bacteria and a particular organism. This representation would be much richer than a representation based merely on the system's cellular density.

3.2.1 *Novelty and complexity*. According to K_3, $c_{t'}$ involves features that are neither involved in b_t nor in $b_{t'}$. Also, there is a considerable change of complexity between b_t and $b_{t'}$.

The relevant new feature of the bacterial system is, following the description of the example, the ability to colonize higher organisms. Such a property is neither involved in b_t nor in $b_{t'}$. And the change of complexity is involved in the increasing intercellular signaling that results thanks to the high density of the population.

Finally, we may focus on the case from the philosophy of mind:

3.3 *Phenomenal state*. Suppose that Mary is observing a landscape and that her seeing can be considered as a set of phenomenal states. Let us call one of those particular states s. Mary's state s is part of (or determined by) a biological system constituted by neural states.

This is the emergence claim that we want to evaluate: In *K*, state $s_{t'}$ is emergent from neural state n_t. As in the other cases, this is true just in case contextual reducibility, contextual irreducibility, novelty and complexity hold, where K_1, K_2 and K_3 are accessible from *K*.

3.3.1 *Contextual reducibility*. According to K_1, state $s_{t'}$ is reduced to n_t.

We have to consider a crucial point here. If every phenomenal state is a state of consciousness, i.e. a state of a system that essentially involves what it is like to be that system, then $s_{t'}$ is not deducible from a system in which $s_{t'}$ does not occur. In other words, the context in which a phenomenal state occurs is essential to it.

In order to put the latter point in clearer terms, let K_p be the phenomenal context in which $s_{t'}$ occurs. The reduction statement considered above could be reformulated like this: In K_1, state $s_{t'}$ according to K_p is reduced to n_t according to K_1.

Since the acquaintance of state $s_{t'}$ can only occur within K_p, it cannot be accessed from K_1, unless K_p and K_1 are the same context. Thus, the reduction of Mary's phenomenal state could, in principle, only be carried out by Mary herself, observing the landscape and, simultaneously, carrying out a functional description of her experience. In other words, the scientific context (say, the neuroscientific context) must be identical with the phenomenological context.

Of course, we could construct some functional description based on Mary's behavior and what she reports while she admires the landscape and assume that such a description refers to her phenomenal state $s_{t'}$. We may call that description "$s_{t'}$ according to K_1". However, "$s_{t'}$ according to K_1" cannot be identical with "$s_{t'}$ according to K_p". Thus, neither reduction as identity nor reduction as replacement could be carried out in this way successfully. A reduction based on derivation could also be carried out moving away from K_p. We could, in principle, derive "$s_{t'}$ according to K_1" from "$n_{t'}$ according to K_1". But that would not be a derivation of the phenomenal state $s_{t'}$ as such.

One could think that this way of considering reduction may be applied to any kind of emergent state. For example, we could say that a system's gaseous state according to some context K_1 cannot be reduced, from the perspective of a different context K_m, to some molecular state of that system. This is true. But we could reduce the gaseous state described in K_1 to the molecular state described in K_1. And this reduction could be as valid as a reduction of the gaseous state described in K_m to the molecular state described in K_m. Neither the gaseous state nor the molecular state is essentially an epistemic state and neither of both is essential to a particular context. Both, K_1 and K_m, could be referring to the same thing. By contrast, phenomenal states are essentially epistemic states, in the sense that they must occur from the perspective of some context[12]. More importantly, the context associated with a phenomenal state is only one, which means that a reduction of a phenomenal state according to a descriptive context K_1 cannot refer to the same thing as a reduction of that phenomenal state according to a phenomenic context K_p. This shows in which way the contextual reducibility of phenomenal states is different from the reducibility of other emergent states.

The irreducibility condition should not be hard to understand now:

> 3.3.2 *Contextual irreducibility*. According to K_2, $s_{t'}$ cannot be reduced to $n_{t'}$.

This will be true whenever K_2 is either different from the context that is essential to $s_{t'}$. Any attempt to reduce $s_{t'}$ from a third person perspective should fail.

According to the account proposed in this work, if Mary's phenomenal state is emergent from the neural state n_t, the conditions of novelty and complexity must also be satisfied:

> 3.3.3 *Novelty and complexity*. According to K_3, $s_{t'}$ involves properties that are neither involved in n_t nor in $n_{t'}$. Also, there is a considerable change between the complexity of n_t and the complexity of $n_{t'}$.

The novel properties involved in $s_{t'}$ could be phenomenal qualities. They can only be found in phenomenal states. They are not like permeability, for instance, which is a quality that can be found in different kinds of states. The novelty of Mary's phenomenal state is guaranteed, when one compares it with neural states n_t and $n_{t'}$.

Regarding complexity, an activity change in Mary's neural system occurring between n_t and $n_{t'}$ might provide the appropriate information to satisfy this condition, if such a change is correlated in the right way with Mary's phenomenal states.

An interesting conclusion of these considerations is that, in principle, Mary's phenomenal state can be rendered as an emergent state only from her perspective, because it can only be reduced from a context that includes the relevant phenomenal context of her experience. From any other context, her phenomenal states cannot be contextually emergent. At best, they could be re-described on the basis of Mary's physiology or behavior and reduced as such. But, given the argument just presented, it is controversial to consider these descriptions as strong emergent states, i.e. states that cannot be reduced in any available subcontext, not even in principle (cf. Chalmers, 2006). Only phenomenal states, essential to a phenomenic context, seem to be

[12] Here, I interpret the concept of epistemic state in a broad sense and not only limited to some kind of propositional attitude.

characterizable as strongly emergent.

4 Other notion of contextual emergence

Robert Bishop and Harald Atmanspacher (Bishop & Atmanspacher, 2006) propose a more constrained account of contextual emergence (see also Harbecke & Atmanspacher, 2011; Atmanspacher, 2015). I will explain its general aspects and then compare it briefly to my account.

Bishop and Atmanspacher aim at establishing a clear interlevel relation between two levels of a system. It is based on two steps:

> 4.1 *Interlevel relation*. A low-level *L* of a system is related to a high-level *H* of that system on the basis of the following steps.
> 4.1.1 An individual description of *L* must be expressed as a statistical description of *L*.
> 4.1.2 The statistical description of *L* must be expressed as an individual description of *H*.

Take, for instance, a flock of birds showing interesting patterns. We can provide a low-level, individual description of the group of birds based on the states of each individual bird. By considering the probabilities of each bird's possible state, we can construct a statistical description of the low level. This can be iterated in such a way that the collection of positions may form patterns, which are observable on the basis of step 4.1.2. Saying, for example, that the flock of birds has a round form is not a description of the low level, but an individual description of the system's high level. The crucial point is that the conditions that allow us to identify the new individual aspects of the statistical description of *L* depend on the high level *H* (Atmanspacher 2015). This is a contextual constraint imposed by *H* on *L*. Such conditions can be seen as *relevance conditions* that determine interesting aspects of *L*. The features identified after performing step 4.1.2 are called *emergent observables*. Considering this, we can characterize the notion of an emergent property in the following way.

> 4.2 *Emergent property*. A property *P* is an emergent property of a system just in case it can be observed on the basis of an individual description of the system's high level, constructed from a statistical description of the system's low level.

There are more similarities than differences between the notion of contextual emergence put forward in this work and the one proposed by Bishop and Atmanspacher. First, both are epistemic notions of emergence. Emergence is understood in terms of epistemic contexts rather than as a relation that could be assigned to sets of states independently of any context. Thus, these notions do not directly provide accounts of *ontological emergence*. I will consider this issue again in the following section.

Second, both notions are defined structurally, in terms of relations between different domains. Emergent states cannot be defined considering only one level of description. One has to characterize them taking the different levels involved into account and explaining how they are related.

Third, both notions of contextual emergence are based on some admittedly relevant notion of observation. Emergent states cannot be understood just descriptively but must also be conceived as phenomena.

Let me now consider two main differences between both accounts. A first difference is that, according to the account of Bishop and Atmanspacher (2006), reduction is considered in a strict form, while my account is not restricted to any particular notion of reduction. They take the following concept: Some description *E* is reduced to another description *B* just in case *B* offers both necessary and sufficient conditions to derive *E*. I have nothing against the possibility of performing a strict reduction like this one within some reductive context, even if *E* could be defined as an emergent state at the level of a broader context. Actually, Bishop and Atmanspacher (2006, p. 1757) argue that, in cases of contextual emergence, low-level descriptions might be necessary, but not sufficient for deriving high-level descriptions, because the contextual conditions are required. Thus, contextual emergence would imply some kind of contextual strict reduction, which we could characterize as follows:

> 4.3 *Contextual strict reduction*. Some description of state *E* is strictly reducible to a description of state *B* just in case the description of *B* offers both necessary and sufficient conditions to derive the description of *E*, according to some reduction context *K*.

We can see that, considering this characterization of reduction, the idea of emergence proposed in this work is in line with the account of Bishop and Atmanspacher, despite the difference just mentioned.

Another difference between both accounts on contextual emergence is related to irreducibility. This is a feature to which Bishop and Atmanspacher do not pay much attention, because when there is a case of irreducibility, high-level and low-level states seem to be completely disconnected. By contrast, I think that a contextual notion of irreducibility such as the one I assume is crucial to understand emergence. In particular, this sense of irreducibility is important to distinguish interesting causal features of the high-level state that are not explainable in the reductive context. Consider, for example, an economic crisis. We may be able to reduce the set of states that constitute the crisis to some set of states *B*, according to some reductive context mainly based on the interactions between economic agents. But we could also attend to the causal influence of the economic crisis in certain political issues. The descriptions associated with such an influence might be considered from the vantage point of a different context, according to which the economic crisis is functionally irreducible. Of course, nothing precludes considering another reductive context in which those influences can also be reduced. However, even finding those cases we might also find a complementary context, according to which different causal features are rendered as irreducible.

In regard to the account of Bishop and Atmanspacher, the importance of irreducibility contexts should be considered as a consequence of their notion of contextual reduction. For, if there is a context involving conditions that allow us to strictly reduce *E* to *B*, then there must be a context involving conditions that do not allow us to do that. Clearly, contexts of the latter sort are not always relevant, but only in cases in which they are, we might be able to identify emergent states, together with their irreducible causal roles. Downward causation is possible on the basis of irreducibility contexts, as when we say that the economic crisis caused a firm's bankruptcy without giving a low-level explanation of such an effect. This way of understanding the problem of downward causation is similar to the perspective on mental causation proposed by Harbecke and Atmanspacher (2011)[13].

It may seem clear that the differences just considered do not imply deep contrasts, but actually express, under the right assumptions, interesting compatibilities between both accounts of contextual emergence.

5 Ontological emergence

As already mentioned, the notion of emergence proposed in this work is an epistemic notion and not an ontological notion of emergence, i.e, it is characterized on the basis of how we approach phenomena and seek knowledge about them rather than on how things are with independence of our understanding and knowledge. Now, what does it mean that something is independent from our knowledge? I am not going to answer this question here, of course, but it is problematic enough to justify introducing the following characterizations in hope of some clarity.

> 5.1 *Ontological state*. A state *s* is an ontological state just in case for any set of epistemic states *e*, *s* would not change if *e* changed.

Ontology is concerned with the study of ontological states. The notion of an ontological state refers to reality in general. I would not deny that there are ontological states. However, we have to distinguish between ontological

[13] Other differences between both accounts are related to the notions of observation, complexity, normativity, novelty and, particularly, to the stepwise characterization of the interlevel relation proposed by Bishop and Atmanspacher. I will not elaborate on these differences here.

states and descriptions referring to ontological states. We can characterize these type of descriptions as follows:

> 5.2 *Description of ontological state*. A proposition describes an ontological state *s* just in case it attributes properties to *s*.

An *ontological* or *metaphysical notion* is a notion that depends on how we describe ontological states. If we talk, e.g., about an ontological notion of subatomic particle, we claim that there are ontological states of a certain kind that have certain properties. The attribution of these properties cannot be something that occurs with independence of what we know or of our epistemic capacities. And if we acknowledge this, we have reasons to focus on some epistemic contexts rather than others.

I propose that any ontological notion of emergence should be defined considering how we describe ontological states. I cannot deny that there might be ontological states of emergence, i.e. states to which we may refer on the basis of epistemic contexts that may not vary with variations of those contexts. In that sense, *ontological states* of emergence would be independent from our knowledge, just as any other ontological state. However, it seems more than plausible to think that any *ontological concept* of emergence must depend on what we know, as any other describable concept.

The main idea of this section is to show how one may consider claims evaluated from particular contexts and accommodate them to determine whether a property is emergent in the ontological sense. This should be appropriate if we are disposed to accept that ontological notions and assumptions are not independent from our epistemic capacities. I will not focus on the details of any complete ontological analysis of emergence in particular. My aim in this section is rather to consider how ontological emergence and contextual emergence might be related.

Warren Shrader (2010, p. 287) identifies a set of necessary conditions for an ontological account of emergence, which he calls *minimal ontological emergence*. These are the following:

> 5.3 *Minimal ontological emergence*. Let S_E be some set of properties and S_P be the set of all physical properties. If E, a member of S_E, is an emergent property, then the following conditions must hold.
> 5.3.1 E is not ontologically reducible to any member of S_P.
> 5.3.2 Instantiations of E are determined either by a member of S_P or are connected by a chain of determination to the instantiation of another member of S_E that is determined by an instantiation of a member of S_P.
> 5.3.3 Some instances of E have causal features that no physical event has.

Let us start considering condition 5.3.1. According to Shrader, a widely accepted notion of ontological reduction among proponents of ontological emergence is identity. A property Y is ontologically reducible to a property X, if and only if *Y* is identical to *X*. Thus, being irreducible, emergent properties are not just physical properties. This notion of reduction is stronger than the notion of functional reduction characterized before (2.5). Although I focused on functional reduction, there can be cases of emergence, such that, according to a reductive context, a particular emergent property is identical to some set of physical properties. Additionally, according to another context, such emergent property would be functionally irreducible to that set of physical properties and, therefore, would not be identical to it. On the basis of the account presented here we may also consider other notions of ontological reduction, such as elimination (2.6), composition (2.8) and supervenience (2.9). Anyhow, contextual reduction does not express what condition 5.3.1 expresses. Note that on the basis of a contextual notion of emergence, emergent properties *must* be reducible. And as mentioned, reducibility is considered in a general sense, including representational and ontological notions. By contrast, on the basis of minimal ontological emergence, emergent properties are just not reducible.

Plausibly, ontological notions depend on what is assumed, presupposed or concluded within epistemic contexts[14]. For instance, I assume that there is a (real!) hill near me because I am seeing it. And I can conceive my seeing it as a process that occurs with relation to an epistemic context. I am used to trust contexts of visual perception on the basis of my experience with communication and action. Given that we can evaluate contexts in this way, suppose that we are able to consider, for any subject matter *M*, a most reliable epistemic context focused on it, symbolized as K^*_M., on the basis of which we may postulate our best ontology[15]. Although this kind of context may be based on the empirical results of a scientific community, empirical information is not the only relevant sort of information within it. We may characterize the notion of ontological reduction as follows:

> 5.4 *Context-based ontological reduction*. A property *Y* is ontologically reduced to a property *X* just in case *Y* is identical to *X* according to K^*_X.

I do not intend to replace the standard ontological notion of reduction as identity. Plausibly, if two ontological properties are identical, we can reduce one to the other. However, we have to consider that the notion of identity itself could be put under evaluation within K^*_X, as well as the properties according to which *X* and *Y* are described. Thus, whatever notion of identity is relevant at a given point according to some highly reliable context, property

[14] I am thinking of something near the well-known notion of *ontological commitment* (Quine, 1948; Atmanspacher & Kronz, 1999).

[15] If there are two or more equally reliable contexts about the same topic, we may try to break the indifference by focusing on the broader context in which they are being assessed. Although crucial, the detailed issues related to context selection are beyond the scope of this work.

identity implies property reduction for that context, i.e. ontological reduction.

This definition is close to what we may call a context-independent notion of reduction, even if, rigorously speaking, it is not. It implies that properties that are emergent in some epistemic sense may not be emergent in an ontological sense. Note that ontological reduction is projected from a more reliable context regarding *X* and not regarding the reduced property *Y*[16].

Let us now focus on condition 5.3.2. According to Shrader (2010, p. 289), any determination relation must be an asymmetric dependence relation:

> 5.5 *Determination*. For any couple of entities *X* and *Y*, if *X* determines *Y*, then
> 5.5.1 *Y* depends on *X* and
> 5.5.2 the dependence of *Y* on *X* is stronger than the dependence of *X* on *Y*.

Functional reduction, as defined before, can be seen as related to some kind of determination between states, when *X* and *Y* (or the causal roles of their instantiations) are not identical. Determination, as just characterized, is necessarily an asymmetric relation, while functional reduction is not. I will not discuss here other notions of determination and reduction, according to which the latter statements may not hold.

Clearly, contextual reducibility is not enough to express condition 5.3.2. Let us put it this way, focusing on states rather than properties[17]:

> 5.6 *Context-based ontological determination of emergent states*. Any emergent state *E* must be, within the most reliable context K^*_E,
> 5.6.1 functionally reducible, but not identical, to some set of physical states or
> 5.6.2 connected to other properties that are reducible in that way.

Let us now focus on condition 5.3.3. It establishes that some instances of emergent properties have causal features that no physical property has. In order to characterize this idea, we have to recur to the ordering of contexts:

> 5.7 *Context-based ontological irreducibility*. A state *E* is ontologically irreducible just in case there is at least one context *K* that is accessible from the most reliable epistemic context K^*_E, such that, according to *K*, *E* is functionally irreducible to the set of physical states that determine *E*,

[16] One may object that whether something is ontologically emergent should depend on something objective and not be projected from our epistemic assumptions. As a quick response, I would say that scientists project ontologies all the time and not subjectively, but *intersubjectively*. What is a subatomic particle? It is whatever our best scientific context says it is. Objectivity, in this sense, does not mean independence from theory, but a kind of epistemic validity about what we have.

[17] The characterization regarding states can be translated to a characterization regarding properties, following 2.4.

according to K^*_E.

These conditions may seem too strict. However, considering that it is *ontological*, and not just epistemic irreducibility, it seems acceptable to demand this much. So, *ontological reducibility of states* will imply, in a strict sense, that E must be reducible in *all* contexts that are accessible from K^*_E. By contrast, according to the present proposal, epistemic reducibility only implies that reduction is possible in at least one accessible context.

Note that this version of ontological irreducibility is not the opposite of ontological reduction, as defined in 5.4. Following Shrader, ontological reduction is a thesis about properties, while ontological irreducibility is a thesis about states. Let K be a subcontext of K^*_E and let E be some state. It is possible that, according to K^*_E and to a notion of reduction as identity, some property involved in E is ontologically reduced (in terms of identity) but, according to K, E is functionally irreducible. This would imply that E is ontologically irreducible according to K^*_E. E would not be emergent in Shrader's sense, but could be considered emergent in an epistemic sense, following the analysis proposed in this work. On this basis, ontological emergence is a special case of epistemic, contextual emergence.

6 Concluding remarks

Contextual emergence has been presented here as a non-trivial, epistemic concept of emergence. Challenges related to the apparent inconsistency of emergence can be tackled on the basis of this account. Additionally, it is compatible with an ontological notion of emergence, according to which one may project determined ontologies from particularly rigorous contexts. It has also been shown in which sense reduction and irreducibility are aspects that are as relevant for a broad account of contextual emergence as for an ontological account.

Acknowledgments

I would like to thank Alan Baker, Ali Esmi, André Fuhrmann, Dominik Kauß, Harald Atmanspacher, George Ellis, Karen Crowther, Miguel Fuentes, Óscar Orellana, Raúl Fuentes, Robert Van Gulik, Ronald Durán and Rubén Herzog for discussions, comments or clarifications on some of the main issues involved in this work. I am also indebted to audiences at the 9th European Congress of Analytic Philosophy, held in Munich, and at the 14th Colloquia Psychiatrica, held in Viña del Mar. Research leading to this article was financed by CONICYT, the Chilean Commission for Scientific and Technological Research (FONDECYT projects #3160180, #1181414 and #11180624).

References

Atmanspacher, H. & Kronz, F. "Relative onticity," in *On quanta, mind and matter*, edited by Atmanspacher, Amann & Müller-Herold, Springer, 1999, 273-297.

Atmanspacher, H. "Contextual emergence of mental states." *Cognitive Processing* 16 (2015): 359–364.

Beckermann, A. (1992). Introduction: Reductive and Nonreductive Physicalism. In *Beckermann, Flohr & Kim (eds.). Emergence or reduction?: Essays on the prospects of nonreductive physicalism.* Walter de Gruyter. (DOI: 10.2307/2108450)

Bedau, M. "Weak emergence." *Philosophical Perspectives* 11 (1997):375-399.

Bedau, M. "Downward causation and the autonomy of weak emergence." *Principia* 6 (2002):5-50. (DOI: 10.1111/0029-4624.31.s11.17)

Bishop, R. & Atmanspacher, H. "Contextual Emergence in the Description of Properties." *Foundations of Physics* 36 (2006):1753-1777. (DOI: 10.1007/s10701-006-9082-8)

Broad, C. D. (1925). *The mind and its place in nature*. Routledge and Kegan Paul.

Butterfield, J. "Less is Different: Emergence and Reduction Reconciled." *Foundations of Physics* 41 (2011):1065-1135.

Chalmers, D. (2006). Strong and weak emergence. In P. Davies & P. Clayton (eds.), *The Re-Emergence of Emergence: The Emergentist Hypothesis From Science to Religion*. Oxford University Press. (DOI: 10.1007/s11153-007-9129-6)

Chaitin, G. J. (1969). "On the Simplicity and Speed of Programs for

Computing Infinite Sets of Natural Numbers". *Journal of the ACM* 16 (3): 407-422.

Crowther, K. "Decoupling emergence and reduction in physics." *European Journal for Philosophy of Science* 5 (2015):419-445. (DOI: 10.1007/s13194-015-0119-8)

Dowe, P. *Physical Causation.* Cambridge University Press, 2000.

El-Hani, C. N. & Pereira, A. M. "Higher-level descriptions: why should we preserve them," in *Downward Causation*, edited by Andersen, Emmeche, Finnemann & Christiansen, University of Aarhus Press, 2000.

Fuentes, M. A. (2014). Complexity and the emergence of physical properties. *Entropy*, 16(8), 4489-4496. (DOI: 10.3390/e16084489)

Fuqua, C., Parsek, M. R., & Greenberg, E. P. (2001). Regulation of gene expression by cell-to-cell communication: acyl-homoserine lactone quorum sensing. *Annual review of genetics*, *35*(1), 439-468.

Gell-Mann, M. & Lloyd, S. (1996). Information Measures, EffectiveComplexity, and Total Information. Complexity.Harbecke, J. & Atmanspacher, H. "Horizontal and vertical determination of mental and neural states." *Journal of Theoretical and Philosophical Psychology* 32 (2012):161-179. (10.1037/a0027157)

Holland, J. *Complexity: A Very Short Introduction*. Oxford University Press, 2014.

Kim, J. (1999). "Making sense of emergence." *Philosophical Studies* 95 (1999):3-36. (DOI: 10.1023/A:1004563122154)

Kim, J. *Physicalism, or Something Near Enough*. Princeton University Press, 2005. (DOI: 10.1515/9781400840847)

Kim, J. "Emergence: Core ideas and issues." *Synthese* 151 (2006):547–559. (DOI: 10.1007/s11229-006-9025-0)

Kolmogorov, A. N. (1965). "Three Approaches to the Quantitative Definition of Information". Problemy Peredachi Informatsii 1 (1): 3-11.

Luisi, P. L. (2006). *The emergence of life: from chemical origins to synthetic biology*. Cambridge University Press.

Nagel, E. (1961). *The Structure of Science*. New York: Harcourt, Brace and World.

Ney, A. "Physical causation and difference-making." *British Journal for the Philosophy of Science* 60 (2009):737-764. (DOI: 10.1093/bjps/axp037)

Perry, J. (2001). *Reference and Reflexivity, Stanford, CA: CSLI Publications.*

Quine, W. V. O. "On What There Is." *Review of Metaphysics* 2 (1948):21-38.

Sartenaer, O. (2016). "Sixteen Years Later: Making Sense of Emergence (Again)." *Journal for General Philosophy of Science / Zeitschrift für Allgemeine Wissenschaftstheorie* 47 (2016):79-103. (DOI: 10.1007/s10838-015-9312-x)

Shoemaker, S. *Physical Realization*. Oxford University Press. 2007.

Shrader, W. "Shoemaker on emergence." *Philosophical Studies* 150

(2010):285-300. (DOI: 10.1007/s11098-009-9413-7)
Van Gulick, R. (2001). Reduction, emergence and other recent options on the mind/body problem: A philosophic overview. *Journal of Consciousness Studies* 8 (9-10):1-34.