Is it possible to account for all phenomena in terms of fundamental physical laws?

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Abstract

In this paper I attempt to find an answer to the research question: "*Is it possible to account for all phenomena in terms of fundamental physical laws?*". In particular, I dissect the question into an epistemological dimension and an ontological dimension. While the former is interesting for the allocation of scientific funding, the latter is interesting to philosophers. I begin by describing the concepts of reduction and emergence, differentiating in the varying ways in which both can occur, as they pertain to my research question. I then look at several different academic fields which show problems with the reductionist view. I first describe the notion of spontaneous symmetry breaking in the natural sciences. Following that I look at the similarity between (social) complexity and emergence. Lastly, I present some arguments from the philosophy of mind about the possibility of explaining consciousness in physical terms. These cases seem to indicate that there are many weakly emergent phenomena, and additionally that consciousness is a good candidate for a strongly emergent phenomenon. This tells us that the epistemological question receives a negative answer. The ontological question however remains unanswered, as there does not seem to be a general consensus on whether consciousness is truly irreducible.

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Introduction

In this paper I will attempt to answer the question: "*Is it possible to account for all phenomena in terms of fundamental physical laws?*". Much has already been written on this question, and I will try to give an overview of some of the established stances and concepts as well as provide some plausible cases and arguments against the positive answer to this question. In the next section I will further explain the structure of this paper.

To understand the significance of this question I believe it is important to make a distinction between two different versions of the question, the ontological and the epistemological. The ontological version can be reformulated as "*Are all phenomena reducible to fundamental physical laws?*". This question is perhaps of most interest to philosophers as it inquires into the structure of our reality. The epistemological can be reformulated as "*Are humans capable of explaining and predicting all phenomena by use of fundamental physical laws?*". The epistemological version is interesting for a wider audience, particularly scientists, politicians and policy makers, as it tells us what humans are capable of, and it can therefore inform us into how we should conduct the pursuit of knowledge. For instance, were the question answered affirmative, we would first have to ask ourselves how practical this endeavour is, and then humanity might focus most of our efforts on discovering these fundamental laws, and, once discovered, use them to explain and predict an increasing portion of our observable phenomena. On the other hand, if the question is answered with a negative, we might focus more of our efforts on different sciences and different ways of explaining phenomena which are more appropriate for the specific subject. One example of how this question has practically influenced the world is with the Superconducting Super Collider , construction of which was cancelled partly due to a convincing argument by Anderson (Robinson, 2015), who claimed that prioritising, in terms of scientific funding and professional specialisation, only the physical sciences which deal with the most fundamental level is unproductive (Anderson, 1987).

It is useful to note that by fundamental physical laws I mean the laws of nature as they are discovered within the physical world, and which are not possible to be subsumed into, or derived from, other laws. With the word *fundamental* I aim to question the reductionist claims, while the word *physical* is directed at the physicalist claims, which will both be explained in the next section.

The object of much of science, especially natural science, is to find these fundamental physical laws. A scientifically discovered law is meant to describe a certain characteristic about reality. Greatly simplifying the matter we can say that scientific laws are founded on extensive empirical evidence, after which a causal relationship is determined and possibly developed into a law, it is then further tested over time, which should either falsify or corroborate the law (Carrol, 2016).

What becomes a scientific law is the matter of much philosophical debate, most philosophers and scientists agree that it should hold some kind of generalisability to more occurences of the same kind of phenomena, and it should also be universally applicable, meaning that it holds anywhere in the universe (Carrol, 2016). There are two main conceptions of what constitutes law: the Humean and the anti-Humean (Beebee, 2000). The anti-Humean claims that laws of nature are those generalisations which are necessary and have governing power in the world. That is, anti-Humean laws of nature constrict what is possible in the world. The Humean denies that there are any necessary relations at all, we have no perfect reason to believe that nature will continue to behave the way it has in the past. The Humean is thus tasked with finding a different account of what constitutes a law of nature, one of the strongest Humean accounts is the Mill-Ramsey-Lewis (or Best Systems) account (Beebee, 2000). According to Lewis (1973) a law of nature is a generalisation which occurs "*as a theorem (or axiom) in each of the true deductive systems that achieve the best combination between simplicity and strength*". Meaning that if we were to know all there is to know about the world, those generalisations which seem to summarise the most, in the sense that they are made as simple and with as much explanatory power as possible, should be considered the laws of nature (Ghins, 2007) (Jackson and Smith, 2007). The Best Systems account thus has no need for a necessary relationship but instead describes laws of nature as common regularities.

Notably, in this paper I do not want to focus on what has been discovered by science so far. Instead I will focus on whether we would be able to account for all phenomena if we knew *all* that there is to know about fundamental physics. Given the Best Systems account we can also rephrase the research question in the following way: "*Assuming we know all there is to know about the world, would, according to the Best Systems account, the laws of nature be only those fundamental laws that physics describes, or will we find that it is easier to explain many phenomena at their respective levels instead of relying on fundamental theories and axioms?*"

In this thesis I will attempt to answer, or at least shed some light on, both the epistemological, and ontological version of the research question, although I will note here that answering the ontological version is significantly more difficult. I will argue that there are very plausible cases which indicate that the epistemological answer is negative, and that there is at least one candidate case, albeit contentious, against the positive answer of the ontological question.

Methodology

In the next chapter I will outline the main stances on the research question, those of reductive physicalism and of non-reductive physicalism. Additionally, I will differentiate between ontological and methodological reductionism, and I will describe the concept of emergent phenomena, the existence of which would render complete reduction impossible. In the following chapters I will present multiple different ways, from varying academic fields, in which reductionism seems to be insufficient to account for certain phenomena. I will first delve into the notion of spontaneous symmetry breaking in the natural sciences, which provides epistemic difficulties for the reductionist. I will describe spontaneous symmetry breaking as it was used by Anderson (1972) in his paper “More is Different” to attack, what he calls, the constructionist hypothesis. I will further expand upon this idea by including some more recent research done by a group using an Ising model to illustrate the relevance and prevalence of spontaneous symmetry breaking. I will then look at complexity theory, specifically social complexity, which also finds the reductionist method lacking in its predictive and explanatory capability, and turns to the use of simulation as a possible avenue for understanding complex phenomena. Lastly, I will present some arguments from the philosophy of mind on the plausibility of consciousness being non-reducible to the physical.

Reduction and Emergence

Reductive Physicalism

In this paper I will mainly question the notion of reductive physicalism. Physicalism is the belief that everything that exists is physical. Reductionism states that phenomena can be reduced to something at a lower or simpler level (Van Riel and Van Gulick, 2019). By being reducible I mean that something can be explained, or accounted for, entirely in terms of something else, conversely something is irreducible if it cannot be explained in terms of something else. In this paper I will use the terms reducible, explainable and accountable interchangeably. Reductionism claims then that all phenomena can be accounted for in terms of the fundamental level alone. In other words, the whole is nothing more than the sum of its parts, and therefore the whole can be explained entirely in terms of its parts. However, reductionism in itself says nothing about what the parts are, they can be mental such as in idealism, or physical such as in physicalism. Reductive physicalism is the view that all phenomena can be explained in terms of their fundamental physical parts (Stoljar, 2017). For the sake of brevity I shall henceforth refer to reductive physicalism simply as reductionism in this paper.

Non-Reductive Physicalism

To contrast the view of reductive physicalism there is the position of non-reductive physicalism. Non-reductive physicalism holds that everything is physical or supervenes on the physical, but not every phenomenon can be reduced to fundamental laws. Put differently, there are different levels of phenomena occurring, and some of these levels might not be explainable in terms of the more fundamental levels, and therefore they warrant their own level of explanation. Non-reductive physicalism can be considered as being committed to the existence of so-called emergent phenomena (Crane, 2001), which I will explain later in this chapter.

The notion of supervenience is important for non-reductive physicalism, as many (but not all) thinkers believe that supervenience is necessary for emergent phenomena. A property A supervenes on property B iff: any change in property A is only possible when there is a change in property B (Mclaughlin and Bennett, 2018). Important to note is that this does not necessarily mean that property A is the same as property B, nor does it mean that property A is reducible to property B, in fact, one could argue that the only reason to use the term supervenience is if the property is not the same.

The concept of supervenience allows the non-reductionist to maintain the view that even though a property (e.g. a mental state) supervenes on another property (e.g. a physical state of the brain) the properties can still be non-identical, even though one does depend on the other (Francescotti, 2020). This allows the non-reductionist to stay committed to physicalism.

Methodological and Ontological Reductionism

Before explaining the concept of emergence and its different varieties I think it is helpful to mention that there are also multiple varieties of reductionism. In this paper I will specifically focus on two versions, as they pertain to my research question: methodological reductionism and ontological reductionism (Polkinghorne, 2002) (Honderich, 1995). Ontological reductionism claims that all of reality is really reducible to its simplest parts, and has a clear connection to the ontological dimension of my research question. Methodological reductionism is the idea that the most efficient scientific practice is to study reality by studying its simplest parts, but it does not make any claim about how reality is structured. Methodological reductionism applies to the epistemological dimension of the research question, by stating that even if it is not in principle possible to explain all phenomena this way, the best method is still to practice science by studying the fundamental physical constituents.

Thus, ontological reductionism claims that all phenomena, whether psychological, sociological, biological, et cetera, are reducible to physical phenomena. Methodological reductionism, on the other hand, claims that science, in practice, should focus on studying the smallest parts in order to understand the world. The aforementioned position of reductive physicalism can also be refined in terms of these two varieties of reductionism into methodological reductive physicalism and ontological reductive physicalism. Commitment to either version of reductionism does not necessarily apply commitment to the other.

Emergence

Emergentism embraces the idea of emergence or emergent properties. Crane (2001) gives a concise definition of emergent properties: "*The intuitive idea of an emergent property is the idea of a 'novel' property of a whole or complex which 'emerges' from the parts of the whole and the way the parts are put together.*" The basic idea is that there are higher-level phenomena, which are different from the lower-level laws and where the relationship between the higher and the lower level is not entirely clear. A popular motto of emergentism is "the whole is more than the sum of its parts", so something new arises at the higher levels which cannot be predicted or explained from the lower levels (O'Connor and Wong, 2020).

Much philosophy has been done on emergence, and there are many different nuances. In this section I will try to mention only the nuances which are relevant to the thesis. Importantly, there are two main varieties of emergence, weak and strong, which are actually very different, I will explain these first. After having explained the two varieties of emergence I will provide a further classification of the different versions of emergence.

Types of Emergence

There are two main types of emergence: weak and strong. Weak emergence is an epistemological characteristic. A phenomenon is weak emergent if it cannot be predicted and/or is unexpected from the fundamental laws alone and instead requires or is better suited to a different form of inquiry (Chalmers, 2006). Whether weak emergent phenomena exist determines the relevance of the different sciences and their relationships to each other. If they do not exist this means that all sciences can in principle be subsumed under physics, but if they do the other sciences can maintain their own importance.

Weak emergence is often defined by different scientists and philosophers in different ways, therefore I will provide a brief overview of exactly the varieties of weak emergence as they appear in the literature.

- *Unpredictable*: this is the weakest version of emergence and requires nothing very special except that it would be especially hard to predict this emergence through parts alone. This version is also subjective as it depends on exactly how unpredictable something has to be before we would call it emergent. We can say that a phenomenon is unpredictably emergent if it is more practical to attempt to study the phenomenon at its own level, instead of trying to explain it through a more fundamental level.
- *Simulation requirement*: Bedau (1997) has argued that the criteria for a weakly emergent phenomenon should be that it is only possible to predict a phenomenon from lower-level facts and laws through the means of simulation, but that it is entirely impossible to arrive at this result through other means (O'Connor and Wong, 2020). Although I am not convinced that there exist any phenomena which are principally undeducible except through simulation, the use of simulation is so ubiquitous in the study of emergent phenomena that I think it is valuable to mention Bedau's criteria.
- *Undeducible in principle*: this is the strongest of the epistemological claims. A phenomenon is undeducible in principle if it is impossible, even by a supercomputer or a Laplacean demon to arrive at the phenomenon through lower-level facts and laws. A phenomenon is undeducible but not irreducible if we can explain the phenomena through the fundamental level after it has occurred.

Strong emergence is an ontological characteristic. A phenomenon is strong emergent if it arises from, but is not reducible to a more fundamental level. A strong emergent phenomenon is also likely weak emergent, as it is unpredictable from the fundamental level as well (Chalmers, 2006). Whether a strongly emergent phenomenon actually exists is hard to determine, since whenever we find a phenomenon which we do not seem to be able to reduce to its lower-levels, we can always say that it is only very difficult, but in principle possible. Strong emergence can be disproven, if we were to learn to be able to reduce all phenomena to more fundamental facts and laws, however this is still a far way off. Strong emergence is thus mostly an object of philosophical inquiry, outside of the reach of science.

Summary

To avoid confusion for the reader, I think it is useful to present a summary of the concepts I have mentioned. I have so far made clear that there are different varieties of physicalism, reductive and non-reductive. The both stances agree that everything is physical or supervenes on the physical, but while the former claims that all phenomena can be explained in terms of fundamental physical laws alone, the latter claims that this is not possible. Reductive physicalism further comes in two varieties, methodological and ontological. Methodological is a normative claim about how to conduct science, while ontological is a descriptive claim about how reality is structured. Methodological reductionism answers the epistemological research question, and ontological reductionism answers the ontological research question. Both of their answers are positive, with methodological reductionism making the normative claim that humans should try to explain everything in terms of fundamental physical laws.

Non-reductive physicalism, as mentioned, seems committed to emergent phenomena, either weak or strong. The existence of weak emergent phenomena would mean a negative answer for the epistemological research question, while the existence of strong emergent phenomena would mean a negative answer for the ontological research question. I want to add that strong emergent phenomena do not necessarily refute physicalism (as the phenomena might supervene on the physical), but this is certainly possible, such as in the case of mind-body dualism, where besides the physical a mental world is postulated. I will however not delve too deep into this discussion and keep mostly to the discussion within physicalism.

Broken Symmetry as Emergence

In this chapter I will look at the notion of spontaneous symmetry breaking in the natural sciences as a form of emergence. This notion was used by Philip W. Anderson in 1972 to attack the constructionist hypothesis, which I will explain in the next section. Following that I will present some examples to make clear what spontaneous symmetry breaking is. Then I will further specify how spontaneous symmetry breaking relates to emergence and my research question. Lastly, I will mention additional, more recent research done on spontaneous symmetry breaking by a group using a mathematical model.

The Constructionist Hypothesis

In 1972 Anderson wrote a paper titled "More is Different" in which he explains the fallacy in thinking that the methodological reductionist approach will yield all the answers. In his paper Anderson differentiates between the "reductionist hypothesis", the idea that all phenomena can be reduced to lower-level phenomena, and the constructionist converse of this hypothesis, which he aptly names the "constructionist hypothesis". First Anderson explains the prevailing view: "*It seems inevitable to go on uncritically to what appears at first sight to be an obvious corollary of reductionism: that if everything obeys the same fundamental laws, then the only scientists who are studying anything really fundamental are those who are working on those laws.*" But, then he states: "*The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe.*". Anderson thereby states that it is possible to agree with ontological reductionism, while denying our ability to extrapolate from these fundamental laws to explain the rest of the universe. Anderson further goes on to explain that the constructionist hypothesis falls apart when we move to larger and more complex phenomena, he explains that at "higher-levels" new and unexpected properties appear, and that these phenomena warrant research at their own respective level.

Although Anderson never explicitly puts it in these terms, in essence he does seem to agree with ontological reductionism while denying methodological reductionism, as can also be seen from the following: "*He claimed that the laws of solid state physics could never practically be extrapolated from quantum mechanics without reference to empirically established, higher-level phenomena; he fought shy of the stronger claim that higher-level laws could never in principle be derived from below.*" (Martin, 2015). The "constructionist hypothesis" goes directly against methodological reductionism while retaining the possibility to hold on to ontological reductionism.

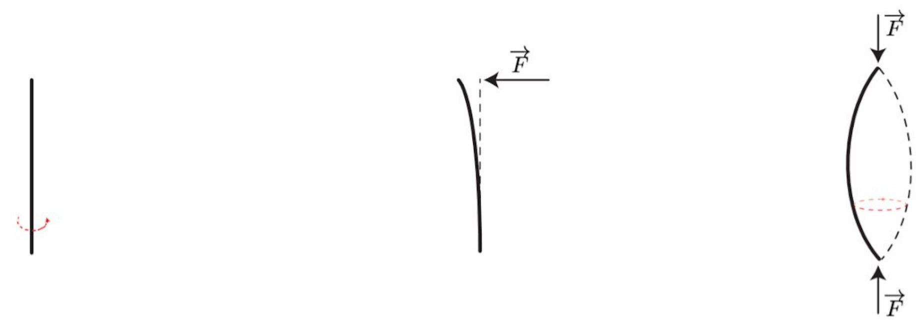
Theory of Broken Symmetry

To support his criticism of the constructionist hypothesis, and the argument that new properties arise at higher levels Anderson explained the theory of "broken symmetry", which claims that "*Asymmetrical states cannot be derived solely from symmetric fundamental laws. They represent "emergent" properties.*". Anderson uses some examples to show that "*a really big system does not at all have to have the symmetry of the laws which govern it: in fact, it usually has less symmetry.*". Anderson further says that it is extremely difficult, if not impossible, to start from the fundamental physical laws and deduce the behaviour of the phenomena he mentions, thereby directly going against methodological reductionism. (Cat, 1998)

Spontaneous Symmetry Breaking

The specific process Anderson explains is also referred to as spontaneous symmetry breaking. Anderson defined spontaneous symmetry breaking as a situation where "*[a]lthough the equations describing the state of a natural system are symmetric, the state itself is not, because the unsymmetric state can become unstable toward the formation of special relationships amongst the atoms, molecules, or electrons it consists of.*" (Anderson and Stein, 1987).

Spontaneous symmetry breaking is opposed to explicit symmetry breaking, where there is an external force applied to a symmetric system which then breaks the symmetry and disrupts the equations of motion. Spontaneous symmetry breaking does not require such a force, and the equations of motion will still obey the original symmetry. A very simple example of spontaneous and explicit symmetry breaking is the case of a rod which has rotational symmetry, such as in the following figure 1(a). In figure 1(b) there is an active external force which bends the rod in a certain way, this is explicit symmetry breaking. In figure 1(c) there is a force applied in the length of the rod, which causes the rod to bend in an arbitrary direction and thereby also losing its symmetry. Important to note here is that in figure 1(c) the rod can bend in multiple different directions around its axis with equal probability, these are called its ground states, and the fact that there are multiple possibilities with equal probability means that the specific direction in which it bends can be considered arbitrary. Furthermore, the different ground states are related to each other by the original rotational symmetry of the rod. If one considers all the possible ground states in a spontaneously broken symmetry system one can still observe the symmetry of the system, it is just that the specific instantiation of the system will not display this symmetry. (Van Dam, 2012; Brading, Castellani and Teh, 2017)



(a) Unbroken symmetry: the rod in its original state is rotationally invariant

(b) Explicitly broken symmetry: the rod bends due to an external force and loses rotational invariance

(c) Spontaneously broken symmetry: the rod bends in an arbitrary direction and loses rotational invariance

Figure 1 (Van Dam, 2012): Symmetry Breaking in a Rod

Molecules

An example used by Anderson (1972) is the ammonia molecule, which he knew many people would be familiar with. I will briefly explain this example here. The ammonia molecule contains 3 hydrogen atoms and 1 nitrogen atom and is shaped like a tetrahedron, as shown in figure 2(a, b). Figure 2(a) and 2(b) show two different orientations of this molecule which correspond to their respective lowest energy states, as can be seen from 2(c). Figure 2(c) as a whole is symmetrical, but the ammonia molecule has two lowest energy states and if it is found in either of these it will seem asymmetric. The middle of 2(c) would be a symmetric state. What will happen in reality is that the nitrogen atom will invert its position w.r.t. the hydrogen atoms due to quantum mechanical tunneling, the ammonia molecule will rapidly change between the two lowest energy states into a kind of superposition between the two states. The ammonia molecule overall is then still displaying its initial symmetry. But when moving on to larger and more complex molecules, such as the sugar molecule mentioned by Anderson, the inversion will become slower and the symmetry will break. Pumain (2006): "*Inversion is very fast for ammonia, very slow for big molecules; the inversion time gives space for symmetry breaking and hence new kinds of phenomena at a "higher" (in this case molecular or chemical) level, due to the number and organisation of lower-level entities involved.*".

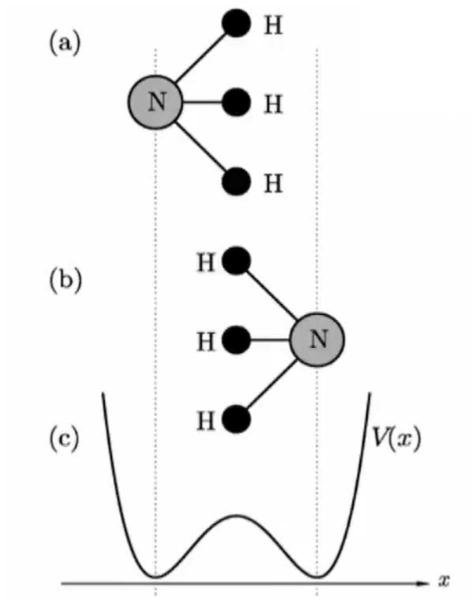
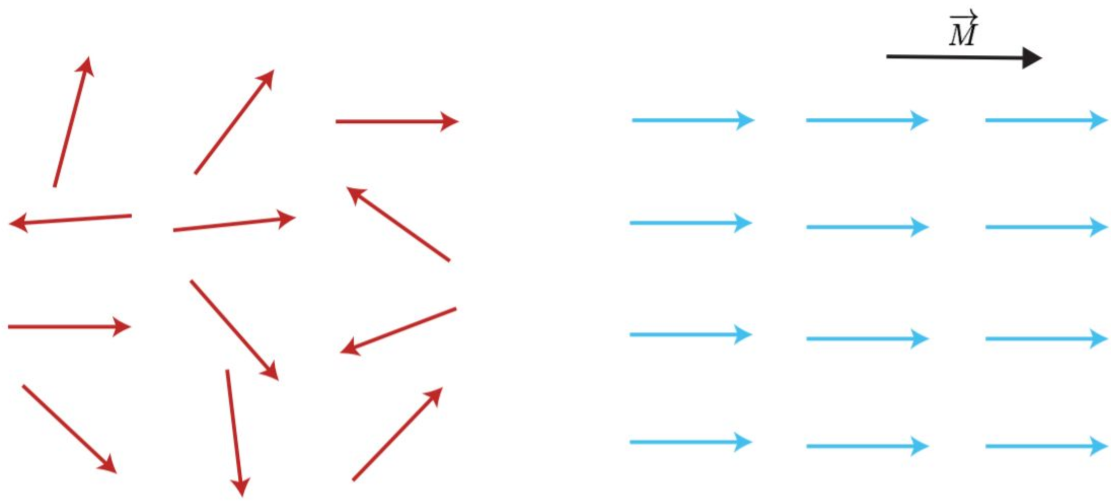


Figure 2 (Blundell, 2018): Inversions of the Ammonia Molecule (a, b) and its Ground States (c)

Anderson used these examples of larger molecules to challenge people to reach the same conclusions about these molecules starting from the fundamental level alone, which he claimed would not be achievable. Anderson's criticism of methodological reductionism is further illustrated by the following: "*Anderson's ammonia example drew its force from the fact that anyone attempting to describe an ammonia molecule's behavior for the first time would, by any reasonable understanding of practice, be required to employ higher-level concepts in addition to so-called first principles.*" (Martin, 2015) Anderson emphasized the problem of the constructionist hypothesis by claiming that it is practically impossible to reconstruct the phenomena of larger, more complex molecules from the constituents alone.

Ferromagnets

Perhaps a more interesting example of spontaneous symmetry breaking is that of ferromagnets. Ferromagnets can be modeled as a collection of spins, as in figure 3. Figure 3(a) depicts a situation where the temperature of the ferromagnet is high, in this case the spins will orient themselves in a random direction, this means that the magnetisation of the ferromagnet will disappear and thus when looked at macroscopically the ferromagnet will appear rotationally symmetric. But if the ferromagnet cools under a critical temperature the spins will align in the same direction, as in figure 3(b), and the magnetisation arises, which points in the same direction as the spins, the symmetry is then broken. In practice, we experience this as magnets having north and south poles, and when it happens the way in which they are rotated is no longer invariant. But, as was the case in the example of the rod, the spins and therefore the magnetisation could have aligned in a number of different directions, which, when looked at together, would still show the underlying symmetry. (Van Dam, 2012)



(a) The ferromagnet for $T > T_c$. The global rotational symmetry is unbroken.

(b) The ferromagnet for $T < T_c$. The global rotational symmetry is spontaneously broken.

Figure 3 (Van Dam, 2012): Symmetry Breaking in a Ferromagnet

Like the ammonia molecule, ferromagnets have a limited amount of ground states, but because there are many directions in which the spins can align the amount of time it will take for quantum mechanical tunneling to align the spins in all the directions will take considerably longer than it takes for the ammonia molecule to invert its orientation. In the case of large macroscopic ferromagnet the time it takes to reach a symmetric superposition like the ammonia molecule can take even longer than the age of the universe, and the ferromagnet can therefore practically be considered to occur in an asymmetric state (Maiani, 2013; Fraser, 2016).

True spontaneous symmetry breaking however is said to only occur in systems with infinite degrees of freedom, as only then the tunneling amplitude will truly approach zero, and only then will the system remain in an asymmetric state. Nonetheless, as shown by the ferromagnet example, systems with a large amount of degrees of freedom can exhibit asymmetric states for a very long time. (Brading, Castellani and Teh, 2017)

Several more phenomena seem to undergo the same kind of symmetry breaking: ordinary crystals for example, but also superfluidity and superconductivity. All of these, in one way or another, show less symmetry than their underlying laws. (Wilczek, 2013; Anderson and Stein, 1987)

Anderson’s Conclusion

In “More is Different” Anderson (1972) made clear that he is against the “constructionist hypothesis”, or against methodological reductionism, but not against ontological reductionism. In other words, he claims that *in principle* every phenomenon can be explained in terms of fundamental laws, but starting from these fundamental laws it is not possible to reconstruct or predict some of the higher level phenomena. Even though the theory of broken symmetry is often claimed to describe emergent phenomena it seems that the phenomena are only emergent in the sense of being difficult, or potentially impossible, to arrive at from the lower-level laws (Bishop, 2019). Anderson even said “*a perverse reader could postulate a sufficiently brilliant genius—a super-Einstein—who might see at least the outlines of the phenomena at the new scale; but the fact is that neither Einstein nor Feynman succeeded in solving superconductivity.*” (Martin, 2015), making clear that he did consider it possible in principle to predict the emergent phenomena at higher scales. By this, I hope to have made clear that at least the importance that Anderson attributed to the theory of broken symmetry was because he thought it showed the existence of unpredictable emergence, but he maintained the position of ontological reductionism and made no claim on the existence of ontological emergence.

More Really is Different

Following-up on Anderson’s theory of broken symmetry Gu et al. (2009) performed research using an Ising model to show that the reductionist approach does not suffice in the case of emergent phenomena. An Ising model is a mathematical model, which the team used to show how complex macroscopic behaviour can arise from initially simple microscopic conditions, which are completely known since it is a designed mathematical system with mathematical rules. In fact, in the infinite, periodic Ising systems the team arrived at the conclusion that macroscopic properties arise which are formally incalculable. And thus these properties are not even in principle possible to be derived from the lower-levels rules. The Ising model was used to describe a system’s magnetisation, but it has further reaching consequences according to Binder (2009): “*Because Ising models have been used to describe not only magnetic materials but also neural activity, protein folding and bird flocking, the consequences of Gu and colleagues' results transcend both computer science and physics.*”. Important to note is that the Ising models were used with infinite systems, and they do not apply equally well to finite systems. However the models still show that incredibly complex behaviour can emerge from simple conditions.

Gu et al. set out to show that the macroscopic properties of their infinite system models cannot be *deduced in principle* from the fundamental rules, but they have nothing to say about whether the macroscopic properties can be *reduced* to them. Gu et al. emphasize the fact that the macroscopic observables cannot be *computed*, *deduced* or *predicted* from the initial rules, but this is only in using the infinite system models. The mathematical model that they use only tells us something about how difficult it is to predict some macroscopic behaviour in complex systems, it does not seem to indicate the existence of ontologically emergent phenomena. Gu et al. try to provide further proof for Anderson's valid criticism of the constructionist converse of reductionism and therefore of methodological reductionism, but they do not seem to provide us with any insight into the plausibility of ontological reductionism. The infinite Ising model does seem to provide us with support for the simulation requirement of Bedau, as can be seen from the conclusion of the paper: "*The development of macroscopic laws from first principles may involve more than just systematic logic, and could require conjectures suggested by experiments, simulations or insight.*".

Social Complexity

Complexity

In this section I want to focus on the connection between emergence and complexity science, as well as delve further into the simulation requirement of emergence and illustrate the usefulness of simulation in the study of complex systems, specifically I will focus on social complexity. Complexity has been defined in a number of ways, but the basic idea is that from a (usually large) number of micro-constituent components intricate and unexpected macro-phenomena arise as a result of the interactions between the micro-constituents. It thus seems to be very similar to the concept of emergence, as can also be seen from the following quote from Bedau (2008): "*the models in complexity science are typically described as emergent, so much so that one could fairly call the whole enterprise the science of emergence.*". Siberstein and McGeever (1999) also pointed out that: "*Many [of the] notions of emergence in complexity theory bear a strong resemblance to the notion of spontaneous symmetry-breaking in physics.*". Complexity science, the study of the complex systems takes the rather philosophical concept of emergence and turns it into a scientific field of study. Complexity science includes, for example, nonlinear dynamics, network modelling and chaos theory.

Emergence in Social Science

Hodgson (2000) has written an extensive paper on how emergence has played a role in social science. He describes several developments of a shift in the social scientific paradigm from a reductionist view to an emergentist view. For example, the change of believing that the evolution of human civilisation was explainable in terms of biological characteristics alone, to the inclusion of social institutions in the analysis of societal evolution, since the evolution of human genetics alone did not seem to match the speed of that of the human society. The evolution of social institutions was not clearly derivable from the evolution of human genetics alone and instead required its own level of study. Furthermore, economics moved away from simply analysing individual behaviour to looking at behaviour at the macroscopic level. It became clear that societies were not easily predictable from their lower-level constituents, societies constitute a complex system, which many complexity theorists argue is best understood by use of simulations.

Simulations

As I have mentioned before Bedau (2008) argues that a phenomenon is weakly emergent if it can only be predicted through the use of simulation. This requirement applies quite well in the study of complexity as simulations are often used to make sense of the complexity. And thus, according to this requirement emergence seems to be ubiquitous in our world. An example that is often used to illustrate how complexity works is Conway's Game of Life computer model. This model starts with very basic rules, an agent can be alive or dead and is surrounded by other agents, if an agent is surrounded by less than 2 or more than 4 alive agents they die, if an agent is surrounded by 2 or 3 alive agents they live, if a dead agent is surrounded by 3 alive agents they are born again. From these very basic and well-understood rules very interesting and complex phenomena seem to arise. In this example however it does not seem implausible that the resulting complexity could still be predicted without the use of simulation, however this model is also overly simplistic and most models use many more, though still well known, basic rules, such as Packard's model of evolution, which uses similar simple basic rules to show how a complex phenomena of evolution can occur, such as the development of traits which enhance fitness in a species. According to Bedau, phenomena like these can only be predicted through the use of simulations, and are thus according to his definition weakly emergent. Simulations seem a powerful tool to describe many complex phenomena, such as the so-called "butterfly effect", which means that small changes in initial conditions can have large impacts on the macroscopic scale.

Squazzoni et al. (2013) further emphasize the need for simulation in understanding the complex social phenomena. Phenomena such as economic crises, civil wars, and environmental problems are difficult to understand because they involve a rich interplay of different groups of people on large scales. While the micro-constituents affect the macroscopic happenings, these will in turn affect the micro-constituents again. The macroscopic phenomenon of a civil war, for example, will cause the individual people involved in the war to behave differently, perhaps more afraid or hateful, which will in turn affect the war again. To understand these complex relations simulation offers a very useful tool. While we would hardly be able to have all the rules of our regular world and thereby be able to accurately predict phenomena, with the right basic rules implemented at the lowest levels, it is possible to run the simulation multiple times. Each iteration we run with slight adjustments in the rules, to see how these adjustments affect the complex system in the long term. In this way we observe how different relationships within the system work. Good models allow us to track large-scale and long-term developments in a certain complex system, which would be very difficult to arrive at through any other method. Understanding these developments can then help us to explain and predict complex phenomena.

Concluding Remarks

Hodgson often seems to confound irreducibility with unpredictability, he thereby seems to claim that many social phenomena are actually strong ontologically emergent. However, I think Bedau has the right idea when he talks about a phenomenon being weakly emergent when it is only possible to be predicted by simulation, but not through other means. When a certain phenomenon is the result of a simulation, in which only the micro-constituents properties are given, it is hard to see how this could be an ontologically emergent phenomenon. For strong emergence to occur in a simulation, extra properties or laws at higher level would need to be manually put into the simulation. Emergent social phenomena which are found through simulation therefore seem to exhibit at most weak emergence according to the simulation requirement, but they cannot be characterised as undeducible in principle or irreducible. It is perhaps also relevant to note that many, though not necessarily all, of the (social) complex phenomena are diachronically emergent, meaning that they arise overtime, while the examples mentioned in the context of spontaneous symmetry breaking were synchronically emergent, meaning that the phenomena emerge simultaneously from their underlying causes (Vintiadis, 2020). For example the butterfly-effect mentioned above, is only apparent long after its cause. The emergence in social sciences and in natural science therefore does seem to have a distinct difference.

Mental Phenomena

In this section I want to discuss the phenomenon of consciousness as a possible strong emergent property. I will first present an intuitive argument for why the subjective experiences belonging to consciousness do not seem to be reducible to physical neural processes. I will then give a popular argument against the plausibility of consciousness being strongly emergent. Lastly, I will present some possible rebuttals to this argument.

Subjective Experience as Strong Emergence

Several philosophers emphasize that there is something fundamental about having subjective experiences which is irreducible to the physical state of the brain. Things such as smelling a flower or tasting some fruit are such subjective experiences, which are called qualia. Nagel (1974) presented this view clearly in his paper “What is it like to be a bat?”, he asked us to imagine what the subjective experience of being a bat would be like. We know that bats use echolocation, and we know the physical facts about how they do this, but it is very hard, if not impossible, to imagine what the use of echolocation would feel like. Similarly, some animals see more colours than humans, we know very well how colour works in terms of wavelengths of lights and receptors in our eyes, but we still cannot imagine what a different colour would look like.

Another famous example for this position is the fictional scientist Mary (Jackson, 1982). Imagine that Mary has lived in an enclosed black-and-white room her entire life. In that room she has extensively studied colour, having access to all scientific research done, she has acquired all the possible physical knowledge about colours, but she has never seen colour herself. Then one day she is able to leave the room and walk outside to see colour for the first time. Will she learn something new from seeing colours for the first time? I think many would agree that the intuitive answer is that she would now for the first time truly experience what seeing colour feels like, but this would mean that the subjective experience was not deducible, even in principle, from the physical knowledge alone. This example, along with Nagel’s, seems to indicate that the mental phenomena of subjective experience might not be explainable in physical terms alone, it seems to be strongly emergent.

But, because not many people think that the mental is completely separated from the physical, philosophers often say that at the very least the mental supervenes on the physical, meaning that no change is possible in mental states without a change in the physical states. In this way we can avoid the idea that the mental and the physical are identical, while maintaining that the subjective experiences are still dependent on what goes on in the brain.

The problem of identifying the relationship between these subjective experiences and the physical world (i.e. brain states) is what Chalmers (1995) dubbed “the hard problem of consciousness”, to emphasize how difficult the problem is. Contrast this with the easy problems, which involve discovering relationships between the functional aspects of our cognition (i.e. information processing, memory), which we are well on our way of discovering.

Mental Causation

The idea that consciousness is a strong emergent property is not by any means undisputed. One of the biggest challenges this position faces is to explain its causal role. There are two main stances to take on this role, one is to deny that consciousness has causal power at all, a position which is known as epiphenomenalism, and the other is to say that it does have causal power.

A strong argument against mental states having causal power is the problem of overdetermination. Overdetermination means that a phenomenon has multiple causes, each of which would be on their own sufficient to cause the phenomenon. Kim (1999, 2008) has constructed extensive arguments for why and how causally efficacious mental phenomena face the issue of overdetermination. First, Kim presents three plausible assumptions:

1. Causal closure: every physical phenomenon that has a cause has a physical cause.
2. Causal exclusion: a phenomenon that has a sufficient cause cannot have another cause that is distinct from the first cause.
3. Supervenience: the emergent mental phenomena supervene on the physical.

The causal closure and supervenience assumptions can also be considered as the requirements of physicalism. The problem is best illustrated by the use of the simple diagram in figure 4. Suppose there is an emergent mental phenomenon M which supervenes on a physical phenomenon P, and which has causal power. The way in which M can exhibit its causal power is to cause another mental event M* or to cause the physical event P* on which M* supervenes, and thereby indirectly also causing M*. The problem here is that because of the causal closure assumption P* also has the physical cause P. Thus either both M and P cause P* or both M and P* cause M*, both of which violates the causal exclusion principle. (Vintiadis, 2020; Keijzer, 2018)

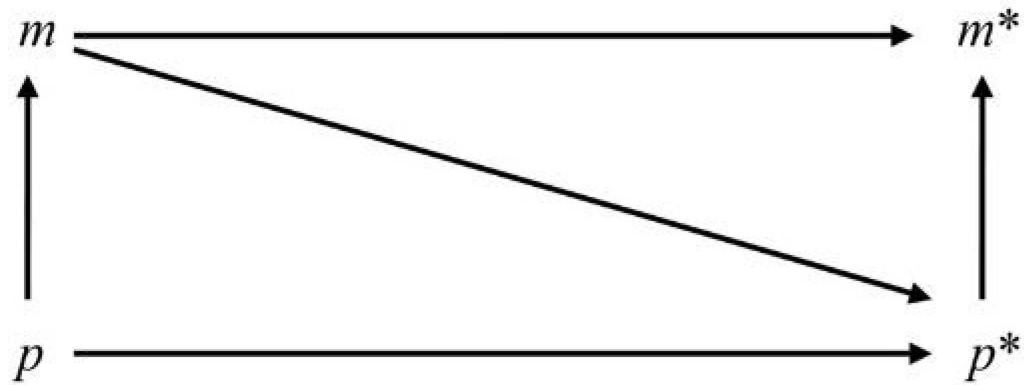


Figure 4 (Moore, 2020): Mental Overdetermination

The reason why the argument bears strength with regards to emergent mental phenomena is because it removes any use for the causal power of them, essentially it makes them obsolete. There are several reasons why philosophers do not like the idea of overdetermination. First, philosophers and scientists alike do not like to postulate things which are not deemed to be necessary, if mental properties do not have causal power it is hard to see why they should exist. Occam's razor states that we should never multiply things beyond necessity, if we do not need it we should not believe it exists. This is further strengthened by the idea that evolution generally encourages traits that enhance our fitness, but if consciousness does not have causal power it also does not seem to contribute to our fitness and thus it serves no evolutionary purpose. Second, we normally do not find many cases of overdetermination in nature, and thus the idea that the mental and physical continually overdetermine things would suddenly change something very rare into something very common, which seems very coincidental. Thirdly, if one cause is sufficient an additional second cause might cause the result to be pushed too far, or it might not be able to have any effect at all. To illustrate this third reason imagine a game of golf in which one putt places the golf ball perfectly in the hole, while two putts is likely to overshoot the hole. (Moore, 2020)

Different Approaches to Mental Causation

There are different possible solutions to Kim's problem of overdetermination. Essentially, all that needs to be done is deny one of the assumptions. The first possible answer I have already mentioned, the position of epiphenomenalism. Epiphenomenalism avoids the argument of mental causation by stating that the mental does not have causal power. The mental supervenes on the physical, but it does not influence either the physical or the mental, it is just there "along for the ride". As I have mentioned however, philosophers and scientists do not like the idea of something existing that is not necessary and serves no purpose. It is also hard to see how this idea could be experimentally falsified, and therefore it is unlikely to gain much traction in the scientific community, which likes its theories to be falsifiable.

Another way to counter the argument is by rejecting the idea of supervenience and instead claiming that the mental is not dependent on the physical, but completely separated from it. This view is essentially dualism, which was first theorised by Descartes (1637). This position however runs into the same problem of being obsolete as epiphenomenalism. And additionally, this position rejects physicalism, which not many people are willing to do.

Lastly, many counter-arguments are aimed at the assumption of causal exclusion. One argument is to say that the causal power involved does not “pack a punch” in the way that Kim claims it does, the causation is not per se productive, but it works in a different way, for example by limiting possibilities (Ladyman, 2008). For example, we can say that the mental has a sufficient cause for other mental states, but they are determined, or made possible, by their physical bases, or the other way around. Another solution is that mental causes are a part of the physical causes, and yet are distinct from them, as they are more limited. Thus the physical cause is still the only sufficient cause. (Moore, 2020)

Experiments on Mental Causation

Interestingly though, there does seem to be some scientific support for the idea that the mental does not have causal power as is pointed out by Libet (1985) and Wegner (2003). Libet conducted experiments in people, which showed activation of relevant brain regions (relatively) long before not only a certain bodily action, but also before the conscious choice of this action. Wegner uses further examples from clinical neuropsychology, such as people experiencing “alien hand syndrome”, where a person’s hand seems to have a mind of its own, or people with schizophrenia that can experience thoughts which do not seem their own (hearing voices). Wegner concludes that it is at least in these cases evident that it is not our consciousness which causes these actions, but that we do experience correlation between consciousness and actions, which we then falsely attribute to causation. In other words, According to Libet and Wegner, mental phenomena, even if they are irreducible to the brain, do not have causal power. But as is usually the case in philosophy of mind, these arguments are not without their critics. (Keijzer, 2018)

Concluding Remarks

There are many more arguments and counter-arguments, and the one mentioned above are discussed far more extensively and more nuanced than I can present here. However, I hope to have made clear that there indeed seems to be a strong intuitive argument for why consciousness is something that is “over and above” the physical and why it therefore might be an irreducible and strong emergent property, but that there are also good arguments against this idea and that again these arguments are also not undisputed. Whether consciousness is a strong emergent property is still unclear and it is unlikely to become apparent anytime soon, but philosophers and scientists will continue to discuss the phenomenon of consciousness and hopefully slowly provide us with more clarity and better tools to discuss the philosophy of mind.

Conclusion and Discussion

In my attempt to answer the research question "*Is it possible to account for all phenomena in terms of fundamental physical laws?*" I found that it would be best to split the question into an epistemological version: "*Are humans capable of explaining (and/or predicting) all phenomena by use of fundamental physical laws?*". And an ontological version:"*Are all phenomena reducible to fundamental physical laws?*". After presenting and explaining the main stances on these questions, I looked at several critiques against the reductionist answer, arising from different academic fields.

I have noted that there are two versions of reductionism, methodological and ontological, which respectively relate to the epistemological and ontological version of the research question. The reductive physicalist will hold either or both of these claims, by which they state that all phenomena are accountable in terms of fundamental physical laws. The non-reductive physicalist, on the other hand, maintains either epistemological, weak emergence or ontological, strong emergence, similarly relating to the likewise named versions of the research question. The non-reductive physicalist claims that it is not possible to account for all phenomena in terms of fundamental physical laws alone, because of the existence of emergent phenomena.

Epistemology

After looking at several different fields I conclude that it seems to be overtly clear that unpredictable phenomena, the weakest version of emergence, do not only exist, but also seem to be a common occurrence, both in natural science, as the discussion on spontaneous symmetry breaking showed as well as in the study of (social) complexity. Given the wide adoption of simulation models in studying phenomena, Bedau's interpretation of weak emergence involving the simulation requirement also seems to have adequate support. Especially the infinite Ising system seems to indicate, at least in principle, there can really be phenomena which are only predictable through simulation. Simulation seems to be a very strong tool in studying phenomena which are otherwise unpredictable from the fundamental levels alone, however the expectation that these phenomena are otherwise in principle undeducible is not conclusive. I think we have thus found plenty of reason to discard methodological reductionism, as we now discover that weak emergent phenomena are ubiquitous. Therefore, prioritising our efforts towards the fundamental level of physics no longer seems to be the most effective approach in science. The answer to the epistemological question is that humans are practically not capable of explaining or predicting all phenomena by use of fundamental physical laws alone, it seems to be more efficient to explain and predict emergent phenomena from a higher level, or to use well-designed simulations.

Ontology
As for the more difficult question of whether there are any in principle undeducible and/or irreducible phenomena, the current focus seems to be on only two possible phenomena, that of quantum entanglement and of consciousness. Until now I have not said much about quantum entanglement, but I would be remiss if I did not add a quick note on quantum entanglement in my discussion on ontological emergence. Besides mental phenomena quantum entanglement is sometimes seen as one of the only candidates for strong emergence (Chalmers, 2006). I have wanted to avoid delving too deep into quantum mechanics as it requires extensive technical knowledge and the implications are far from clear, both for philosophers as well as physicists. Lewis (2016) and Silberstein and McGeever (1999) have written very interesting papers to argue why quantum entanglement is a strongly emergent phenomenon. Essentially, they claim that an entangled pair of particles (a whole) will have causal power over its parts, instead of the other way around. The properties of the entangled state are then not reducible to the properties of the particles. However, whether this is really a case of emergence is questionable, as the entangled state can now instead be seen as fundamental, and the parts as being reducible to the whole. Seen from this interpretation, reduction can remain unscathed. Lewis seems to solve this by equivocating emergence with holism. Because of how tricky this subject is I will leave it aside in my conclusions. For a more thorough discussion I would recommend reading Lewis and Silberstein and McGeever.

Moving on to mental phenomena and the philosophy of mind, there do seem to be solid arguments for the irreducibility of mental phenomena, but there are also strong arguments against this position. I have mentioned the intuitive arguments for the irreducibility of subjective experience, as well as discussed the problems of mental causation. Although we cannot yet make any conclusive claims about consciousness being irreducible I think it is interesting to discuss some potential consequences of the varying stances. There are multiple scenarios we can consider as I have already mentioned:

1. The mental is reducible to the physical
2. The mental supervenes on the physical, and has no causal power (epiphenomenalism)
3. The mental supervenes on the physical, and has causal power
4. The mental is separated from the physical (dualism)

The third scenario as I have mentioned is problematic because of the issues involving mental causation. Dualism has widely fallen out of favour because if the mental and physical are separated it is difficult to imagine how they can influence each other in any way, but they do seem to correlate and thus most philosophers tend to believe that at least the mental supervenes on the physical. On the other hand, if we imagine that the mental does not have a causal power, as in the first and second scenario (in both scenarios the only causal power is physical), it becomes hard to argue for the existence of a free will. If human consciousness is nothing more than what happens in the brain, or if there is only subjective experience that has no causal role, how can we imagine that we have any kind of conscious free will? If we then were to accept that there is no free will this has a whole range of consequences, not just philosophical, but for example also on our ideas of moral responsibility. These ideas are naturally much more discussed elsewhere in philosophy, and far more extensively, but it is interesting to note here that the philosophical arguments concerning the reducibility of the mind do have far-ranging consequences, both philosophical as well as practical.

Returning to the subject of this thesis. It seems for now that the discussion of whether there are any strong emergent phenomena, does not seem to be settled, and is unlikely to be settled anytime soon. We will have to understand both the brain and quantum mechanics more deeply to understand these phenomena better, but, importantly, this research has to go hand-in-hand with philosophy, so that the conclusions drawn from scientific research are well understood and well focused, Similarly, philosophers would be wise to draw upon the extensive knowledge of scientists more to provide ever deeper and more accurate discussions on these phenomena. For now however, we cannot confidently answer the ontological version of the research question.

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