What is Emergence?

by

Keith Latzer Keydel

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written by Keith Latzer Keydel
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Carol Cleland

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Graeme Forbes

____
Robert Parson

Date________________

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What is Emergence?

Thesis directed by Professor Carol Cleland

Abstract:

Despite the fair amount of conceptual fuzziness currently associated with emergence, the concept has recently garnered attention in many fields as a framework for understanding complex systems. In this thesis, I examine various accounts of emergence in both scientific and philosophical literature and some of the major objections to the concept of emergence. Most accounts of emergence can be divided into those accounts which treat emergence as a metaphysical or ontological concept and those which treat emergence as merely epistemic. While metaphysical emergence provides a robust autonomy for higher-level phenomena, it faces some particularly strong metaphysical objections. Epistemic emergence avoids these metaphysical objections, but may be too weak to be of much interest to the philosopher or scientist. Finally, I will build upon Humphrey's metaphysical account of emergence, and argue that this approach is both robust and that it can avoid many of the problems traditionally facing metaphysical emergence.

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CHAPTER I.

Introduction

The concept of emergence is a somewhat nebulous but has recently garnered a fair amount of attention in fields as diverse as philosophy, cognitive science, biology, computer science, and even chemistry. Academics in these fields use the term 'emergence' in many different ways. Even within analytic philosophy, where conceptual clarity is of great importance, there is no widely agreed upon account of emergence. 'Emergence' is commonly used is in the context of poorly understood phenomena such as consciousness and life, sometimes as a form of hand-waving, covering up gaps in our knowledge, or to give a new name to discredited ideas such as vitalism. Critics of emergentism point to this sort of use as a problem with the concept; they suspect that it conceals dualism or mysticism under a false veneer of 'respectable' physicalism. I argue that the concept does not have to, and indeed should not, be used in this manner. Despite its current lack of clarity, the concept of emergence shows promise in helping us understand certain relations between complex higher level phenomena and the lower level, more basic phenomena, upon which they seem to depend.[1]

In this thesis, I examine various accounts of emergence in both the philosophical and scientific literature. Many accounts of emergence can be classified as either an account of epistemic emergence, or an account of metaphysical emergence (sometimes the term ‘ontological emergence’ is used instead of ‘metaphysical emergence’). Epistemic emergence is usually contrasted with predictability or explainability; a phenomenon is epistemically emergent if and

[1] I use the term 'phenomena' in a very broad sense to stay neutral, for the time being, on what sorts of entities participate in the emergence relation. The *relata* vary considerably between accounts; they may be properties, property instances, events, objects, processes, systems, facts, or something else.

only if it cannot be predicted or explained. Metaphysical emergence, on the other hand, is supposed to be an objective feature of reality. If there are metaphysically emergent phenomena, they are emergent regardless of what theories we use to predict or explain them. The epistemic concept of emergence is often referred to as weak emergence, while the metaphysical concept is often referred to as strong emergence. However, not all philosophers use terms 'weak emergence' and 'strong emergence' in the same way. For example, Mark Bedau provides an account of what he calls 'weak emergence' (sometimes he uses the oxymoronic term 'robust weak emergence'), which he argues is ontological and not merely metaphysical. "This kind of robust weak emergence reveals something about reality, not just about how we describe or explain it. So the autonomy of this robust weak emergence is ontological, not merely epistemological." (Bedau 2003) Thus, I will use the terms 'epistemic emergence' and 'metaphysical emergence' to avoid this sort of confusion.

While some philosophers (particularly the 'British Emergentists') treat emergence as though it is a single concept, we need not do so; there many be two or more philosophically interesting concepts that are both called 'emergence'. To an extent I agree with Bedau and Humphreys that we should not assume that there is only a single interesting concept of emergence that needs defining and analysis. While both epistemic and metaphysical emergence may be of interest to the philosopher, I focus on metaphysical emergence because, as I argue below, metaphysical emergence is more robust and useful for understanding the relationship between higher and lower level phenomena, and for shaping philosophical and scientific methodology. Metaphysical emergence, if we can construct a coherent account of it, might provide a framework for studying and understanding complex wholes that are, in a robust sense, more than the sum of their parts.

In section II, I will examine some of the earlier accounts of emergence; particularly the accounts of the 'British Emergentist' tradition. I also examine the fall of this tradition in the mid 20th century, and the shift from robustly metaphysical concepts of emergence to epistemic concepts of emergence in this period. In section III, I will explore several contemporary accounts of emergence, both of metaphysical and epistemic varieties. I will look at some of the main ideas common among accounts of emergence and highlight some *desiderata*. In section IV, I build upon Paul Humphrey's account of emergence, and show how this account of emergence can be applied to issues in philosophy of biology and philosophy of mind using the concept of self-organization. Finally in section V, I address various objects to Humphrey's account of emergence and suggest some ways in which he could address these objections.

CHAPTER II.

Early Emergentism

Like the related terms 'reduction' and 'supervenience,' 'emergence' is a term of art in philosophy, and is only loosely connected to the vernacular term 'emergence'[2]. However, there is no widely agreed upon definition of 'emergence' among scholars, and the various accounts of emergence have changed over time. In order to make sense of the current plurality of accounts of emergence, it is useful to take a historical perspective. The material presented in this section is intended as background information, useful for understanding the current debates about emergence. As such, it is somewhat superficial; I focus on the core ideas of early emergentism. Here we see origins of themes common to many contemporary accounts of emergence.

McLaughlin traces the concept of emergence to 19th century British empiricists, a tradition which he dubs “British Emergentism”(McLaughlin 1992). This tradition begins with John Stuart Mill’s *System of Logic,* published in 1843[3]. At the time Mill was writing Newtonian mechanics was the dominant theory of physics, and this theory shaped philosophical thinking about science during this period. Of particular interest to Mill is the principle of the Composition of Causes; the net result of several forces acting upon an object can be determined using simple vector addition. While this principle appears to be perfectly general, applying to any forces acting on any objects whatsoever, surprisingly it has many apparent exceptions.

> “This principle, however, by no means prevails in all departments of the field of

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2 The vernacular term 'emergence' means, according to *Webster's* “The act or process of emerging,” and the verb 'emerge' means “1. To come forth or rise up from immersion. 2. To become obvious or evident. 3. To issue, as from obscurity. 4. To come into existence.” The philosophical notion is loosely related to the fourth definition of emerge, specifically in the context of higher level phenomena coming into being from lower level phenomena.

3 Even though the idea of emergence can be traced back to Mill, the term 'emergence' was not used in the philosophical sense until G.H. Lewes's *Problems of Life and Mind* about 30 years later (McLaughlin 1992)

> nature. The chemical combination of two substances produces, as is well known, a third substance, with properties different from those of either of the two substances separately, or of both of them taken together. Not a trace of the properties of hydrogen or of oxygen is observable in those of their compound, water. The taste of sugar of lead is not the sum of the tastes of its component elements, acetic acid and lead or its oxide; nor is the color of blue vitriol a mixture of the colors of sulphuric acid and copper. This explains why mechanics is a deductive or demonstrative science, and chemistry not. In the one, we can compute the effects of combinations of causes, whether real or hypothetical, from the laws which we know to govern those causes when acting separately, because they continue to observe the same laws when in combination which they observe when separate: whatever would have happened in consequence of each cause taken by itself, happens when they are together, and we have only to cast up the results. Not so in the phenomena which are the peculiar subject of the science of chemistry. There most of the uniformities to which the causes conform when separate, cease altogether when they are conjoined; and we are not, at least in the present state of our knowledge, able to foresee what result will follow from any new combination until we have tried the specific experiment." (Mill 1843)

In order to explain this apparent violation of the principle of Composition of Causes, Mill postulated heteropathic laws which govern entities at the level of the special sciences, such as chemistry, biology and psychology.

Heteropathic laws, according to Mill, are fundamental laws governing the behavior of chemical compounds and "those far more complex combinations of elements which constitute organized bodies" which are not derivative from the laws governing the parts.

> "This difference between the case in which the joint effect of causes is the sum of their separate effects, and the case in which it is heterogeneous to them—between laws which work together without alteration, and laws which, when called upon to work together, cease and give place to others—is one of the fundamental distinctions in nature." (Mill 1843)

McLaughlin explains that in a framework of forces, this implies the existence of 'configurational forces', forces which arise only from certain configurations of particles (McLaughlin 1992). These configurational forces interact with each other and the particle-pair forces of physics to determine the behavior of physical bodies. These forces produce effects not only on higher-level entities, but also on the lower level components which they are composed; the British Emergentists were committed to what is now called 'downward causation'.

George Henry Lewes built upon Mill's ideas in *Problems of Life and Mind*, published in 1875. In this book, Lewes coins the philosophical term 'emergence'. The focus of Lewes' work is on psychology, and to a lesser degree biology, there is less focus on chemistry than was present in Mill's work. Lewes acknowledges the possibility that chemical properties may be reducible to physics, he argues that life is truly emergent, and is impossible to deduce from the laws of physics and chemistry alone:

> “Among the broad distinctions of phenomena those of Physical, Chemical, and Vital must be maintained, expressing as they do the characteristic motions of propulsion, motions of combination, and motions of evolution. A chemical combination, even if finally reducible to physical laws, is markedly distinguished by presenting new structural relations. A still broader demarcation is given in the vital phenomenon of Evolution (characterized by Nutrition, Development, and Decay, through serial changes), distinguishable from the chemical combinations out of which it emerges. Not only is it impossible to deduce the phenomenon of Evolution from the phenomena of chemical combination, not only is it impossible to explain Nutrition by Chemistry, unless we replace the Laboratory by the Organism, and thus introduce the special evolutive conditions, namely, the presence of organic substance formed into histological elements, (cells, fibres, tubes)” (Lewes 1875)

While we see some epistemic notions, such as deduction and explanation, in Lewes' account of emergence, he is working with a fundamentally metaphysical concept of emergence. The 'special evolutive conditions' of the organism generate new forces which act upon the chemical components of the organism. “A type of effect of two or more types of causes is an emergent, in Lewes's sense, if and only if it is not the sum of the types of effects of each type of cause has according to the laws in which it figures as a separate agent” (McLaughlin 1992).

Lloyd Morgan further builds upon the work of Mill and Lewes. He contrasts emergence with mechanism, mechanism here closely resembling Mill's principle of the Composition of

Causes.

> "The essential feature of a mechanical or, if it be preferred, a mechanistic interpretation is that it is in terms of resultant effects only, calculable by algebraical summation. It ignores the something more that must be accepted as emergent. It regards a chemical compound as only a more complex mechanical mixture, without any new kind of relatedness of its constituents. It regards life as a regrouping of physico-chemical events with no new kind of relatedness expressed in an integration which seems, on the evidence, to mark a new departure in the passage of natural events. Against such a mechanical interpretation such a mechanistic dogma emergent evolution rises in protest." (Morgan 1923)

This assertion that there 'something more' present in the complex wholes, and focus on the 'new kinds of relatedness' indicates a sort of holism in Morgan's account of emergence. This 'more-than-the-sum-of-its-parts' holism remains a major element in many contemporary accounts of metaphysical emergence. Furthermore, his contrasting emergence with mere algebraic summation seems to resemble Wimsatt's definition of emergence as non-aggregativity (this will be discussed more in the next section).

The last major work in the British Emergentist tradition, according to McLaughlin, was C.D. Broad's *Mind and Its Place in Nature* (1925). Like Morgan, Broad contrasts emergence with mechanism, but gives a somewhat more detailed account of what mechanism is and how emergence differs from mechanism. McLaughlin provides a nice, concise summary of how, on Broad's account, emergence functions "Wholes can possess force-generating properties of a sort not possessed by any of their parts. The properties in question will be the properties of being composed of certain sorts of constituents in certain spatial or spatio-temporal relations" (McLaughlin 1992). While emergence, on Broad's account, is metaphysical, epistemic notions, such as predictability, become much more central on his account: "the characteristic behaviour of the whole *could* not, even in theory, be deduced from the most complete knowledge of the behaviour of its components, taken separately or in other combinations, and of their proportions and arrangements in this whole." (Broad 1925). However, this unpredictability stems not from our lack of knowledge, but the novel causal powers possessed by emergent phenomena. In the contemporary talk of emergent properties, this could be rephrased in the following way: A property is emergent just in case its instantiation in a particular composite object is unpredictable considering only its parts in isolation, or in other systems no more complex than the system in question.

Despite the success and popularity of British Emergentism in the late 19th century and early 20th century, this tradition has mostly vanished. McLaughlin attributes this to developments in science, particularly quantum mechanics and molecular biology. "It is one of my main contentions that advances in science, not philosophical criticism, led to the fall of British Emergentism" (McLaughlin 1992). The ability of quantum mechanics to predict and explain chemical bonding has rendered the existence of configurational forces "enormously implausible." Likewise, advances in molecular biology provide a mechanistic explanation for processes occurring in living organisms. As McLaughlin states, "there seems not a scintilla of evidence that there are configurational forces; and there seems not a scintilla of evidence that there is downward causation from the psychological, biological or chemical levels" (McLaughlin 1992). However, it is interesting to note that the type of mechanistic explanations given by quantum mechanics and molecular biology differ significantly from the 'ideal of pure mechanism' which the British Emergentists rallied against.

Another factor which may have contributed to the decline of British Emergentism in the middle of the 20th century was the rise of the "positivist and hyper-empiricist view of science that dominated the Anglo-American philosophy of the time" (Kim 1999). Reductionism enjoyed widespread popularity during this period, bolstered both by the scientific developments mentioned above, and by some trends in the philosophy of science. Notably, the Deductive-Nomological (DN) Model of explanation, widely accepted during this period, asserted symmetry between explanations and predictions. A scientific explanation, on this account, should be structured as a deductive argument in which the *explanandum* (a statement of the phenomenon to be explained) is the conclusion, and the *explanans* (the sentences which explain it) are the premises. On this model, emergence seemed confused and counterproductive, of very little use in generating either testable predictions or satisfactory explanations.

> "Influential philosophers of science during this period – for example, Carl Hempel and Ernest Nagel – claimed that the classic idea of emergence was confused and incoherent, often likening it to neo-vitalism, and what they saw as the only salvageable part of the emergence concept – the part that they could state in their own positivist/formalist idiom – usually turned out to be largely trivial, something that could be of little interest for serious philosophical purposes." (Kim 1999)

This 'salvageable' part was epistemic emergence, of a rather weak and theory dependent variety.

Carl Hempel and Paul Oppenheim present one such account of epistemic emergence. They believed that a phenomenon is emergent if and only if it is unpredictable: "Generally speaking, the concept of *emergence* has been used to characterize certain phenomena as 'novel,' and this not merely in the psychological sense of being unexpected, but in the theoretical sense of being unexplainable, or unpredictable."(Hempel and Oppenheim 1965) Taken in an absolute sense of unpredictability, they believed the concept to be vacuous, for the properties of the parts can be taken to include the property of forming certain wholes under certain conditions. Thus to salvage what they could of the concept, they relativized it to a theory: "The occurrence of a characteristic *W* in an object *w* is emergent relative to a theory *T*, a part relation *Pt*, and a class *G* of attributes if that occurrence cannot be deduced by means of *T* from a characterization of the *Pt*-parts of *w* with respect to all the attributes in *G*." (Hempel and Oppenheim 1965) This revised notion of emergence is rather weak, it is merely an indication of the limits of our current theories. We should expect fewer phenomena to be emergent as we develop better theories which can explain more phenomena.

CHAPTER III.

Contemporary Accounts of Emergence

While there has been a renewed interest in emergence in contemporary philosophy of science, there is no consensus among contemporary academics as to the correct account of emergence. Unlike the British Emergentists, there are few core ideas shared by all contemporary accounts of emergence. We will survey some of the multitude of contemporary positions on emergence, and look for commonalities between them.

There is a divide between accounts which treat emergence as merely epistemic and those that treat it as metaphysical. This divide is not absolute; some accounts contain both epistemic and metaphysical aspects, while others are difficult to put in either camp. Epistemic emergence is usually contrasted with predictability or explainability. However, there is considerable variation among contemporary accounts of epistemic emergence; in particular, there is no agreement on whether this unpredictability is only relative to our knowledge and theories at a particular time (as Hempel and Oppenheim asserted), or absolute (as C.D. Broad held). Andrew Assad and Norman Packard suggest that epistemic emergence can be measured on a scale, from non-emergent properties which are easily deducible from the laws governing the microscopic level to maximally emergent properties which are impossible to deduce from the microscopic level (Assad and Packard 1992).

Andrew Pohorille presents an account of a rather weak variety of epistemic emergence. While this account has its shortcomings, it serves as an example of a contemporary, purely epistemic, account of emergence. According to Pohorille, "In both living and non-living systems emergent properties arise when a number of simple agents (parts of the system) generate complex behavior that cannot be easily predicted from properties of these agents" (Pohorille

2010). This is an exceptionally vague criterion for emergence. How difficult must it be to predict the behavior of the whole from the properties of the parts for the whole to be considered emergent? Pohorille does not provide explicit answer to this question, but his examples suggest that the bar is rather low:

> "As an example, macromolecular and sub-cellular structures and functions exhibit typical characteristics of emergent phenomena. It would be, for example, difficult to anticipate the existence of vesicles from observing single amphiphilic, membrane-forming molecules. Similarly, it would be difficult to predict the structure and function of ribosomes or energy transduction systems only from the knowledge of each individual component" (Pohorille 2010)

While this weak, epistemic emergence many seem almost trivial, Pohorille argues that it can be useful in understanding Darwinian evolution and the origins of life. However, I will not pursue this account further, as I am unconvinced that it is of any use.

Metaphysical emergence, on the other hand, is posited to be an objective feature of reality. If there are metaphysically emergent phenomena, they are metaphysically emergent regardless of our epistemic situation. Yet, it is not always an easy or straightforward matter to distinguish between epistemological and metaphysical accounts of emergence because many accounts of metaphysical emergence employ epistemic concepts. For example, Boogerd et al. (2005) attempt to define emergent properties as those system properties which are not, even in principle, predictable or deducible from a complete knowledge of the system's parts and their properties in isolation or other arrangements. Yet, they make the explicit claim that this is not an epistemological account of emergence;

> "We make use of notions like 'prediction', 'knowledge' and 'explanation' to define emergence. However, this does not turn emergence into an epistemic notion. If a person or a group of scientists is ignorant of some causal factors then a system's behavior might appear emergent. If increased knowledge of the relevant causal factors would make the behavior explainable then this is only an epistemological form of emergence. If a person or a group of scientists knows all

> the causal factors but lacks a theory to explain the system behavior, this behavior might still appear emergent. Once again this is merely epistemic if another theory would make the system behavior explainable. Since we allow complete knowledge of all causal factors and theories, this is an absolute notion of emergence that is not epistemological." (Boogerd et al. 2005)

Boogerd, et al. assert that this is the same basic account of emergence as was used by C.D. Broad (1925), and there is textual evidence to support this interpretation.

There are other metaphysical accounts of emergence that also make use of epistemic notions, or define emergence in epistemological terms. For example Searle (1992) talks about "causally emergent system features" as objective features of the world. But, by "causally emergent system features" he means those system features which "cannot be figured out just from the composition of the elements and the environmental relations; they have to be explained in terms of the causal interactions among the elements." (Searle 1992) On a similar note, Crutchfield states that: "Emergence is generally understood to be a process that leads to the appearance of structure not directly described by the defining constraints and instantaneous forces that control a system." (Crutchfield 1999)

How can these accounts which contrast emergence with predictability or explainability not be epistemic? The assertion that emergence is a feature of the world, and not merely of our understanding of it, suggests that the unpredictability is a symptom of emergence, and not the cause of it nor identical to it. Perhaps these accounts have the explanatory priority between emergence and unpredictability backwards. Maybe the unpredictability doesn't explain the emergence but the emergence explains the unpredictability. For instance, suppose a system has an emergent property which gives it novel causal powers; causal powers that are not present or reducible to the causal powers of its parts. The behavior of such a system would be unpredictable based on even a complete knowledge of its parts and their behavior in isolation or simpler systems, because in isolation, or these simpler systems, they lack the emergent property and its causal powers. If this is the case, then a clearer way of defining emergence is by directly referring to the novel causal powers bestowed by emergent properties.

Paul Humphreys presents one such account of emergence which is robustly metaphysical and is formulated without appealing to epistemic notions. He argues that emergence is a relation of dependency between higher level properties of a system as a whole and lower level properties of the parts which is distinct from supervenience (Humphreys 1996 and Humphreys 1997). Emergence, on Humphrey's account, is primarily a relation between properties. Objects or systems may be said to be emergent, on Humphrey's account if they instantiate emergent properties. Humphreys presents six criteria for identifying emergent properties:

1) Emergent properties are novel – they are the instantiation of a previously uninstanciated properties.
2) Emergent properties are qualitatively different from the properties from which they emerge.
3) It is logically or nomologically impossible for emergent properties to be instantiated at a lower level of organization..
4) Different laws of nature apply to emergent properties than to the properties from which they emerge.
5) Emergent properties result from an essential interaction between their constituent properties, an interaction that is nomologically necessary for the existence of the emergent property.
6) Emergent properties are holistic – they are properties of the entire system rather than local properties of its constituents. (Humphreys 1996)

These criteria are not intended as a definition of emergence; they are not necessary and jointly sufficient conditions for emergence. “I do not suggest that any emergent phenomenon must satisfy all of these criteria, for there is a wide variety of ways in which emergence can occur.” (Humphreys 1996)

Humphreys argues that one way emergence occurs is through what he calls 'fusion operations.' 'Fusion', as Humphreys uses the term here, refers to a 'coming together'[4] of lower level property instances, in such a way as to form a higher level property instance. When lower-level objects fuse to form a higher level whole, they may lose some of the properties they possessed when they were separate and acquire (or come to instantiate) new properties, and many of these properties bestow causal powers. This fusion is taken to be an actual physical process of some sort: “By a fusion operation, I mean a real physical operation, and not a mathematical or logical operation on predicative representations of properties.” (Humphreys 1997) However, the exact nature of this fusion operation may vary from case to case.

It is also important to note that on Humphreys account, the fused property does not supervene on the unfused properties of the parts. To understand this claim, one must remember that supervenience, strictly speaking, is a logical relationship between families of properties and not a physical relation involving concrete objects or events.[5] Supervenience merely asserts that there is some sort of necessary covariance between the extensions of the properties. With emergence, on the other hand, we are interested in the relationship between a property-instance (an event) and the property-instances from which it arises. The fact that certain property instances give rise to other property instances, does not entail that the latter supervene on the

[4] Not necessarily in the literal sense of physically coming into contact; in many cases the lower level entities 'come together' in an organizational or functional sense.

[5] See Kim (1984) “Concepts of Supervenience”, one definition was given in part II.

former. “What I maintain here is this: that one comprehensible version of emergentism asserts that at least some i+1-level property instances exist, that they are formed by fusion operations from i-level property instances, and that the i+1-level property instances are not supervenient upon the i-level property instances.” (Humphreys 1997)

Humphreys uses quantum mechanics to illustrate his account. This hinges on the holistic nature of systems in what are known as 'quantum entanglements';

> “the composite system can be in a pure state when the component systems are not, and the state of one component cannot be completely specified without reference to the state of the other component. Furthermore, the state of the compound system determines the states of the constituents, but not vice versa. This last fact is exactly the reverse of what supervenience requires, which is that the states of the constituents of the system determine the state of the compound, but when the supervening properties are multiple realizable, the converse does not hold. I believe that the interactions which give rise to these entangled states lend themselves to the fusion treatment described in the earlier part of this paper, because the essentially relational interactions between the 'constituents' (which no longer can be separately individuated within the entangled pair) have exactly the features required for fusion.” (Humphreys 1997)

The Bose-Einstein condensate may be another example of this sort. In this unusual state of matter, the de Broglie wavelengths of the atoms overlap and the atoms become truly indistinguishable; there is no longer a matter of fact as to where one atom ends and another begins (Cornell and Wieman 2001). In these cases, it is clear that the system properties, such as position, cannot supervene on the properties of the components, because the components no longer have the relevant individual properties.

These exotic examples make emergence seem like a strange and rare occurrence. This is not what Humphreys intends, to the contrary he argues that “emergent properties are probably quite common in the physical realm.” (Humphreys 1996) Fortunately he presents another, less exotic example of emergence from chemistry: the quantum theory of macroscopic systems which relates the bulk properties of matter to its microscopic constituents. Humphreys argues that the properties of a macroscopic system are emergent because they satisfy most of his criteria for emergence.

> “Some of the most important cases of macroscopic phenomena are phase transitions, such as the transition from liquid to solid. This transition is not exhibited by the micro-components of the liquid (or the solid) since the individual components are the same in each phase. It is their collective relationship to each other that changes across the (usually discontinuous) phase transition. Thus, it is the interactions between the constituents that makes for the qualitatively different macroscopic behavior.” (Humphreys 1996)

Phase transition, unlike quantum entanglements, are common familiar occurrences, both to the scientist and the layperson.

Perhaps even chemical bonding is an example of Humphrey's fusion operation. For instance, a hydrogen atom has (or instantiates) the property of possessing an unpaired valence electron (which gives it the power to form covalent bonds). But, once two hydrogen atoms bond with an oxygen atom to form H_2O, the hydrogen no longer instantiates the property of having the unpaired valence electron, and is not readily able to form more covalent bonds. The water molecule, as a whole, now has the property of having two polar covalent bonds and an electric dipole moment (among other properties it may instantiate), which bestows powers to, for example, form a hydrogen bond with another water molecule. The formation of polar covalent bonds is explainable in terms of the properties of the hydrogen and oxygen (in particular the unpaired valence electrons and the greater electronegativity of the oxygen atom), but the polar covalent bonds do not supervene on these properties.

William Wimsatt takes an approach to emergence, which is hard to classify as either epistemic or metaphysical. According to Wimsatt, “An emergent property is – roughly – a system property which is dependent upon the mode of organization of the system's parts” (1997). More precisely, Wimsatt defines emergence as non-aggregativity. Aggregativity is given a precise definition by Wimsatt:

> **“For a system property to be an aggregate with respect to a decomposition of the system into parts and their properties, the following four conditions must be met:**
>
> Suppose P(Si) = F{[p1,p2, . . . , pn(s1)], [p1,p2, . . . , pn(s2)], . . . , [p1,p2, . . . , pn(sm)]} is a composition function for system property P(Si) in terms of parts' properties p1,p2, ... , pn, of parts s1, s2, . . . , sm· The composition function is an equation – an inter-level synthetic identity, with the lower level specification a realization or instantiation of the system property.
>
> 1. IS (Inter Substitution) Invariance of the system property under operations rearranging the parts in the system or interchanging any number of parts with a corresponding numbers of parts from a relevant equivalence class of parts. (cf. commutativity of composition function).
> 2. QS (Size scaling) Qualitative Similarity of the system property (identity, or if a quantitative property, differing only in value) under addition or subtraction of parts. (cf. recursive generability of a class of composition functions).
> 3. RA (Decomposition and ReAggregation) Invariance of the system property under operations involving decomposition and reaggregation of parts. (cf. associativity of composition function).
>
> 4. CI (Linearity) There are no Cooperative or Inhibitory interactions among the parts of the system which affect this property.
>
> Note that conditions IS and RA are obviously relative to given parts decompositions, as are (less obviously) QS and CI. A system property may meet these conditions for some decompositions, but not for others.” Wimsatt (2000)

Because these criteria are objective and do not depend on our understanding of the system, I am inclined to classify his account as an account of metaphysical emergence. However because these conditions may be met by some decompositions and not others, there are grounds to classify this as epistemic emergence.

Emergent phenomena are quite common on Wimsatt's account. Only a few properties, such as mass and momentum, are not emergent because they are truly aggregative; they meet his four conditions for aggregativity for all possible decomposition of the system into parts. However, on Wimsatt's account, by using simplifying assumptions and setting boundary conditions for analysis, more complex phenomena can be treated as approximately aggregative.

This brings up an important point about this account of emergence. Emergent phenomena, on Wimsatt's account, are not necessarily unpredictable or inexplicable. Emergence is even compatible with certain types of reductive analysis. “Discussions of emergent properties in nonlinear dynamics, connectionist modeling, chaos, artificial life, and elsewhere give no support for traditional antireductionism or woolly-headed antiscientism. Emergent phenomena like those discussed here are often subject to surprising and reveling reductionistic explanations.” (Wimsatt 1997) This is another reason why I believe that Wimsatt treats emergence as metaphysical and not merely epistemic; he seems to be asserting that emergent properties are objective parts of the world, and our ability or inability to predict or explain instantiations of these properties is immaterial to their existence. To put this point more bluntly, just because a phenomenon can be explained does not mean that it can be 'explained away'.

There are often practical difficulties in predicting the phenomena. Many emergent properties display chaotic behavior; that is they are extremely sensitive to minute changes in initial conditions. Hence, in order to predict the behavior of the phenomena one may need accuracy in measurements beyond that of our current capabilities. Furthermore, accurate prediction may require enormous amounts of data and calculations beyond the scope of our best computers. But in principle the phenomena are predictable. The only exception would be for phenomena which are sensitive to quantum indeterminacy. For instance, property pairs such as the momentum and position of a particle are undefined below a certain threshold (half the reduced Planck constant), so systems which are sensitive to such minute changes in a particle's position and momentum would be unpredictable even in principle. However, there is little evidence that many interesting emergent phenomena, such life and consciousness, display this sort of quantum sensitivity.

Despite the differences in the many contemporary accounts of emergence, there are some hallmarks of emergence which are common to most of these accounts. One is physicalism (sometimes called materialism), at least in a very broad sense. All, or almost all (I cannot find an exception), proponents of emergence claim that emergence is compatible with, if not committed to, physicalism. This commitment to physicalism goes all the way back to the British Emergentists; “British Emergentism maintains that everything is made of matter: There are, for example, no Cartesian souls, or entelechies, vital elan or the like” (McLaughlin 1992). However, there is much less consensus as to what exactly physicalism is, and what ontological commitments it has. Many accounts of emergence assert that there are nonphysical properties, and hence reject some stronger versions of physicalism that hold that all properties are physical properties or reduce to physical properties. Most accounts of emergence are compatible with the weaker thesis of token physicalism: “Token physicalism is simply the claim that all the events that the sciences talk about are physical events.” (Fodor 1974). Many disagreements over the concept of emergence are directly tied to issues of physicalism.

Second, explicitly or implicitly central to almost all accounts of emergence (at least of the metaphysical variety) is the assertion that emergent phenomena are real, and that they are distinct from their underlying base. This means that the emergent phenomena are additional elements we must include in our ontology, over and above their parts. The details on exactly how, and in what way, the emergent phenomena are distinct entities varies from account to account, but the assertion that they are distinct is common. This distinguishes emergence both from reduction, which explicitly reduces the higher level phenomenon to lower level phenomena through identity statements (also called bridge laws) and from supervenience, at least those 'ontologically minimalist' accounts of supervenience in which the supervening property is 'nothing but' or 'nothing over and above' its subvenient base (Humphreys 1996).

Third, like supervenient phenomena, emergent phenomena exhibit what might loosely be called multiple realizability. This is to say that several higher level emergent phenomena of one kind may emerge from different kinds of underlying base. I say that this is only loosely multiple realizibility because realizibility is a technical term which does not fit all account of emergence. One definition of realization is as follows: “The usual conception is that *e*'s being *P* realizes *e*'s being *F* iff *e* is *P* and *e* is *F* and there is a strong connection of some sort between *P* and *F*. We propose to understand this connection as a necessary connection which is explanatory.” (LePore, McLaughlin and Loewer, 1989) However, not all accounts of emergence assert that there is a strong, explanatory connection between the higher level and lower level properties.

Some accounts of emergence (such as van Cleeve 1990) use the related term 'supervenience,' and not the term 'realization' to describe emergence. While supervenience accounts of emergence are similar in many respects to realization accounts of emergence, there are some subtle differences. Supervenience is a logical relation between properties (or more precisely, families of properties); “let A and B be families of properties closed under Boolean operations as before: A strongly supervenes on B just in case, necessarily, for each x and each property F in A, if x has F, then there is a property G in B such that x has G, and necessarily if any y has G, it has F” (Kim 1984)[6]. This is to say that there cannot be any difference in the

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[6] Most supervenience accounts of emergence, take it to be a case of strong supervenience because weak

higher-level, emergent properties without a difference in the lower level base properties, but there can be a difference in the base properties without a difference in regard to the emergent properties. This differs from realization in that it involves families of properties rather than individual properties, and that the connection between the properties is purely logical.

These accounts that characterize emergence as a special case of supervenience, typically include the implicit or explicit supposition that supervenience is an important dependence relation, or framework for dependence[7]. Two prominent examples of this approach are presented by van Cleve (1990) and McLaughlin (1997)[8]. The idea, which appears very plausible and attractive at first blush, is that emergent properties supervene on the fundamental physical properties of the system. This is based on what I believe is a correct intuition; two things cannot differ in their emergent properties if the base properties are identical. This seems to match very closely with the basic idea of supervenience; that there cannot be a difference in the supervening properties without a difference in the base properties.

Furthermore, supervenience also seems able to capture the intuition that the same type of higher level property may arise from many different types of lower level properties, or multiple realizability. Jerry Fodor presents a strong argument that this is probably the case with many higher level properties;

> "The reason it is unlikely that every natural kind corresponds to a physical natural kind is just that (a) interesting generalizations (e.g., counter-factual supporting generalizations) can often be made about events whose physical descriptions have nothing in common, (b) it is often the case that whether the physical descriptions

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supervenience is too weak to do much conceptual work; as Kim remarks, "weak supervenience falls short of the following condition: fixing the base properties of an object fixes its supervenient properties" (Kim 1984).

7 For instance, David Chalmers claims that "The philosophical notion of supervenience provides a unifying framework within which these dependence relations can be discussed." (Chalmers 1996)

8 McLaughlin does not, however, commit himself to an emergentist position. To the contrary, he states: "I here simply affirm my faith in reductive materialism." (1997). Rather, he presents what he considers to be the most plausible account of emergence to "sharpen what is at issue in the debate between emergent materialism and reductive materialism."

> of the events subsumed by these generalizations have anything in common is, in an obvious sense, entirely irrelevant to the truth of the generalization, or to their interestingness, or to their degree of confirmation or, indeed, to any of their epistemologically important properties" (Fodor 1974)

Fodor and others argue that higher level properties, such as mental, biological, and even economic properties, are indeed natural kinds, for their are laws (or at least law-like generalizations, if one is not willing to accept *ceteris-paribus* laws) governing them. Many of these higher-level kinds are multiply realizable, for instance there are virtually unlimited possible forms that monetary exchanges can take, yet regardless of the specific form they follow the laws of economics, such as Gresham's law (Fodor 1974).

However, Andrew Bailey presents a strong argument against the thesis that supervenience is a dependence relationship in itself. Because supervenience is a purely logical relationship between properties, or families of properties, it merely expresses that there is covariance between the properties but does not explain the covariance. Furthermore, one family of supervenient properties may supervene on many different families of subvenient properties. For this reason, Bailey concludes that supervenience is not a dependence relation:

> "These problems with deriving dependence from supervenience can be treated as specific cases of the following observation: supervenience, it turns out, is everywhere, but supervenients are usually taken as *depending* only on some particular type of subvenient, specified in a particular way. Thus, supervenience cannot itself be dependence. For any given supervenient, it is possible to pick out several different subvenients." (Bailey 1999)

We may be able to add a dependence relation on top of supervenience to explain emergence. For instance, it seems plausible to suggest that emergent properties supervene upon the base properties, and that the emergent properties mereologically depend upon the base. However, there are some difficulties involved in taking this approach (for instance problems with downward causation which I discuss in section V) .

Paul Humphrey's account, discussed above, take the relation between the higher level phenomena and the lower level base to be neither realization nor supervenience, in the technical sense, because on his account the lower level property instances go out of existence when they 'fuse' to form the emergent property. However, these accounts still allow for multiple instances of an emergent phenomenon of one kind to emerge from a wide variety of lower level kinds.

A fourth commonality between the various accounts is that emergent phenomena display considerable complexity. It is this promise to help make sense of complex, integrated systems that gives emergence much of its appeal in the sciences; “Emergence is receiving renewed attention today, in part because the notion repeatedly arises in certain contemporary approaches to understanding complex biological and psychological systems; I have in mind such approaches as neural networks, dynamical systems theory, and agent based models – what for simplicity I'll call complexity science.” (Beau, 2003) Over the last few decades, the amount of data gathered on a wide variety of subjects, disciplines as disparate as medicine, economics and climatology, has increased exponentially (Bollier, 2010). While computers can help us extract trends from the data, and assist us in deriving equations to show how the many variables depend upon each other, we struggle to put this vast amount of information together into coherent theories. Both philosophers and scientists make use of conceptual frameworks (or theories) to understand how the data fits together and to connect scientific discoveries to the everyday world; “as a scientist, I want to know what these pictures represent; I especially want to know that the mathematical equations represent (some small portion of) reality.” (Kelso, 1995)

Fifth, emergence is closely tied to holism. In some sense or another, emergent phenomena are 'more than the sum of their parts.' A hallmark of emergent systems is that their parts behave differently in isolation or in simpler subsystems. This has significant implications for scientific methodology. Under the reductivist model that has been dominant in the sciences for a long time, the general approach was to decompose complex systems into their constituent parts and study these parts in isolation. In contrast, an emergentist methodology favors studying the system as a whole, as the parts may not behave the same way in isolation. This can be seen in the proliferation of fields which emphasize methodological holism, such as integrative physiology, comparative cognition, and systems ecology.

Sixth, emergent phenomena have novel causal powers. Exactly what is meant or entailed by the novelty of the causal powers differs between accounts. Many accounts claim that novel causal powers involve or entail 'downward causation'; higher-level structures have causal influence on their parts. The exact details of how the higher level phenomena have causal effects on lower level phenomena is a matter of much controversy. Here the difficulty lies as much in the issue of causation as in the issue of emergence. Many differences and disagreements arise over the correct way to characterize causation; what the causal relata are, and how they are connected are still the subjects of many disagreements in metaphysics. Many philosophers, take a regularity based approach to causation. However, some account of emergence, including McLaughlin's (1997), hinge on distinguishing between metaphysical and nomic necessity, and for this a regularity theory of causation appears to be insufficient. For this reason, counterfactual accounts of causation are often used, and emergence is often analyzed in terms of property distribution across possible worlds.

Additionally, there are a cluster of characteristics that are more loosely associated with emergence. These include self-organization, nonlinear dynamics (especially chaotic behavior), context dependency, feedback and organizational properties. While these features are common to many contemporary accounts of emergence, they appear to be less central to the concept of emergence in itself. However, they may help explain how it is that properties or phenomena emerge in particular cases.

To further complicate the issues, the term 'emergence' is applied to both the relationship between certain wholes and their parts, and also to the development of complex systems from simpler precursors. Unfortunately, the fact that there are these two uses of the term 'emergence' is seldom discussed in the literature. The former use is called synchronic emergence, for the relationship is present in a single slice of time, while the latter is called diachronic emergence, for the relationship is between an earlier state and a later one (Bedau and Humphreys 2008). Synchronic emergence pertains to systems and their properties at a given moment in time. Diachronic emergence, on the other hand, refers to processes of development by which the system obtains new properties and causal powers. While the synchronic usage of emergence is much more widely discussed in the philosophical literature, the diachronic usage is more common in the sciences.

We are now in a position to propose some *desiderata* for a good account of emergence. Because 'emergence,' like 'supervenience,' is a technical term, its meaning can be stipulated without regard to the vernacular usage of the term (McLaughlin 1995)[9]. Since we are unconstrained by the vernacular, the *desiderata* pertain to the fruitfulness of the concept in philosophy and the sciences. This raises the question of what sort of conceptual role is emergence supposed to play. Ideally, an account of emergence should be both philosophically rigorous and useful in designing scientific research programs (Bedau and Humphreys 2008). Merely 'hand-waving' accounts of emergence clearly lack philosophical rigor and any utility in the sciences. However, as discussed above, there are many, much more substantial accounts of

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[9] This contrasts with terms like 'causation' which the philosophical usage matches closely with the vernacular usage of the word.

emergence. For instance, the British emergentists, as discussed above, used the term in a precise and consistent manner.

The concept of emergence, as used by both the British emergentists and more contemporary proponents of emergence, can play numerous important roles. It can be used to determine the correct level of analysis of certain phenomena, and in this regard justify the role of the special sciences functioning independently from fundamental particle physics. Emergence motivates methodological holism; some systems cannot be understood by studying their parts in isolation. Furthermore, emergence can provide justification for maintaining higher-level entities (such as organisms, beliefs, and even molecules) in our ontology. While the older reductivist approach has played an important role in the development of modern science, especially in the development of physics, it has also imposed limitations on other sorts of scientific progress. By expecting all sciences to take the same general methodological approach as physics, we have been slow to understand the vast interconnectedness of phenomena in fields such as ecology and economics. Furthermore, the reductivist model suggests that we should see a consolidation of fields. On this model, the special science merely provide partial, or cursory, explanations of phenomena until science progress to the point where the phenomena can be fully explained and predicted by fundamental physics. "Though reductionism is an empirical doctrine, it is intended to play a regulative role in scientific practice. Reducibility to physics is taken to be a constraint upon the acceptability of theories in the special sciences, with the curious consequence that the more the special sciences succeed, the more they ought to disappear." (Fodor, 1974) Yet, we have witnessed the proliferation of fields more often than the consolidation of fields or reduction of these fields to physics. This suggests three main *desiderata* for an account of emergence:

1) it can be fruitfully employed to guide our research methodology

2) it can justify the autonomy of the special sciences, and
3) it can help us understand the relation between complex higher order phenomena and the microphysical base out of which they are formed.

On purely epistemic accounts of emergence, such as Hempel and Oppenheim (1965), emergence serves merely to show gaps or inadequacies in our theories. This may be of some use in guiding research methodology; we can focus on developing theories which can better explain and predict the emergent phenomena. However, such an account is of little use in establishing any sort autonomy for the special sciences. As more powerful theories of fundamental physics develop, the special sciences should be expected to disappear. Epistemic accounts of emergence which take the unpredictability of emergent phenomena to be absolute are even less useful in shaping scientific methodology: “it encourages an attitude of resignation which is stifling for scientific research.” (Hempel and Oppenheim 1965) Furthermore, the epistemic approach provides little justification for retaining higher level entities in our ontology. Even though we do not currently understand how the lower level phenomena produce the higher level phenomena, there is still the sense that the higher level phenomena are 'nothing but' the lower level phenomena. “Because C arose out of B, and B out of A, people are inclined to think that C is nothing but A in a disguised form.” (Broad 1925)

Metaphysical accounts of emergence, on the other-hand, can fulfill all three of these *desiderata*. Because an emergent whole behaves differently from the sum of its parts, emergentism has clear implications for scientific methodology. We cannot obtain a solid understanding of complex systems in disciplines such as biology or economics by studying the parts in isolation. Metaphysical accounts of emergence also can also justify the autonomy of the special sciences, and help explain the proliferation of disciplines. This is because as our knowledge and understanding of the world increases, we will likely discover more emergence in phenomena once thought to be merely the sum of their parts; “we tend to start with simple models of complex systems – models according to which the parts are more homogenous, have simpler interactions, and in which many differentiated parts and relationships are ignored.” (Wimsatt 1997) For instance, when we study biological phenomena at several levels, we become aware of patterns and regularities at the higher levels (in organisms and ecosystems) which are not present in the lower levels (in the individual cells and molecules). Many of these higher level regularities are law-like (that is, they can support counterfactual claims), yet are not analyzable at the lower level. Finally, metaphysical accounts of emergence provide us with strong justification for retaining higher level entities in our ontology. As was discussed in the preceding section, emergent phenomena are something 'over and above' their underlying base, and hence must be in included in our ontology. This may not be an attractive feature for those who prefer minimalist ontologies, but for those, myself included, that believe that we need to include entities such as persons, beliefs, economies and ecosystems in our ontology, this is a strength of the metaphysical accounts.

CHAPTER IV.

Emergence in Life and Mind: Self-Organization and Feedback

As was mentioned in the introduction, the concept of emergence is most often used in regards to issues involving life or mind. However, it is not so straightforward to apply the concepts of emergence discussed in the previous section to these issues. Consider cell biology; the cell as a whole displays many system properties which give the cell causal powers not present at the level or the atoms or molecules. For instance, the cell has the property of maintaining homeostasis, which gives it the power, so to speak, to maintain chemical gradients far from equilibrium. This is a holistic property, one cannot point to a particular molecule or structure within the cell and say “this is what gives the cell homeostasis.” However, unlike the examples in the preceding section, the components of the cell do not appear to lose any of their distinctive properties or powers to give the whole the property of homeostasis. Rather, the property of homeostasis depends upon precise spatial, temporal, and causal arrangement of the parts of the cell. The processes which form and maintain these patterns are generally referred to as 'self-organization'. I believe that self-organization is the key for understanding emergence at these higher levels of analysis.

Unlike 'emergence,' the meaning of the term 'self-organization' is fairly clear and its use in the sciences is closely related to the vernacular use; a thing can be said to be self-organizing if it arranges itself and actively maintains its internal order. More precisely, self-organization involves processes which move the system away from thermodynamic equilibrium. Such processes are energetically unfavorable, and hence must be coupled to more favorable processes to conform to the laws of thermodynamics (in particular the second law of thermodynamics). This account of self-organization is similar to, and compatible with, Ruiz-Ramiro’s account of self-organization; “By 'self-organization' we refer to a phenomenon occurring when a series of non-linear microscopic processes generate a global–macroscopic correlation (a new “pattern of dynamic behavior”) in far from equilibrium thermodynamic conditions that are maintained by the continuous action of a set of constraints, one of which—at least—is a result of the actual phenomenon.” (Ruiz-Mirazo, et al. 2004) Self-organization is a fairly rare phenomena in nature, but has recently garnered a fair amount of attention in the scientific community. It appears most often in biology, as functional self-organization is one of the hallmarks of life. However, there are also cases of abiotic self-organization, such as the Belousov–Zhabotinsky reaction.

In addition to the coupling of processes, feedback is necessary for self-organization. Feedback allows the system to regulate its internal processes, so that it does not quickly burn through its internal store of free energy and then reach equilibrium. A good example of this can be seen in metabolic networks. The citric acid cycle, a central part of all known metabolisms, displays both positive and negative feedback regulation. The cycle displays positive feedback, as key products from each step serve as substrates for the next. This allows for up-regulation when pyruvate (the primary input for the cycle) is plentiful. Negative feedback is used to down-regulate the cycle when its products are abundant in the cell. Two products of the cycle, ATP and NADH, act as allosteric inhibitors.

The requirements of feedback and a coupling of processes for self-organization helps to explain the complexity associated with emergence. Simple systems lack the variety of processes needed to be self-organizing, and hence do not display this sort of emergence. It is, however, unclear what minimum level of complexity is needed for self-organization. It is possible that self-organization is a matter of degree. The synchronization of pendulum clocks on a beam is far less complex than a living cell, and displays some self-organization, but to a lesser degree.

The self-organization and feedback type interactions between the parts of the system which emergent properties depend upon can account for the novel causal powers of the system. In this framework, we can understand downward causation and see that it is not deeply mysterious or inexplicable. Downward causation is usually understood as a species of causation in which the system as whole bears causal influence over its parts. Jaegwon Kim explains that "Downward causation occurs when a higher-level property, which may be an emergent property, causes the instantiation of a lower level property." (Kim 1999) In the case of system properties which depend upon feedback, the feedback structure of the system sets the conditions for the particular actions of the parts. For example, the negative feedback regulation of the citric acid cycle can be seen as a form of downward causation. An instantiation of a system property, the abundance of free energy in the cell (in the form of NADH and ATP), has a causal effect on the parts of the system, in particular slowing the production of these compounds in the citric acid cycle. It is important to note that the relevant causal property, having an abundance of NADH and ATP, is a property of the cell as a whole, and not of its parts. We cannot say of any molecule, even a molecule of NADH or ATP that it has an abundance of NADH or ATP. Rather, it is the relation of the NADH and ATP to the other parts (molecules) in the cell that explains the abundance of free-energy. But as I argued above, this sort of explanation is not contrary to emergence.

Emergent properties depend on the system functioning as a unified whole. The various parts of the systems studied in biology and psychology are not independent of each other. To the contrary, they depend heavily on each other and the structure of the system as a whole. For instance, in network theory the effect of perturbations on one part of a system will spread to the rest of the system. Feedback mechanisms then cause the changes in the other parts to affect the part originally perturbed. The effect, even on a single part, cannot be deduced by considering only a part (or few parts) of the system in isolation – nothing less than observing the whole system will do. For this reason, it makes sense to treat such systems as individual composite objects; the interdependence of the systems parts required for this sort of self-organizational emergence provides some justification for including such composite objects in our ontology.

This sort of functional holism is most apparent in biology. For instance, adding salt to the cytosol does not linearly increase the salinity, because the cell reacts to the increased salt by activating sodium-potassium pumps which actively pump sodium ions out of the cell and prevent the entry of chlorine ions. However, this effect cannot be deduced by studying the cytosol, or the membrane in isolation. Furthermore, the sodium-potassium pumps require energy (in the form of ATP) to run, so extra-systemic information (information about the environment), such as the availability of food to make ATP is needed to accurately predict the behavior of the cell. Mental phenomena also exhibit holistic, self-organizational processes. Mental properties arise from neural processes in the brain which exhibits complex networks of feedback interactions among the constituent parts. However, there are also simpler, more mundane examples of this sort of emergence; for instance the synchronization of pendulum clocks on a beam and the Belousov–Zhabotinsky reaction display some self-organizational properties.

This model of emergence could also be a boon in understanding how features of complex systems 'come together', even when this sort of coming together is not obvious on the microlevel. For instance, in philosophy of mind and cognitive science, it allows us to understand how our sensations 'come together' for us, so that we experience the world as a unified whole, even though the information does not come together in any one location in the brain. By adopting the emergentist framework, we can treat consciousness as a property of the brain as a whole, rather than continuing to attempt to localize consciousness in a particular region of the brain. Furthermore, this avoids the regress given by asking which part of the part is responsible for consciousness. Likewise it allows us to treat a cell, as a whole, as living without granting that there are any living molecules.

Self-organization can also help us to understand the relation between the synchronic and diachronic uses of the concept of emergence. While the synchronic sense of the term emergence is more common in the philosophy literature, the diachronic sense of emergence is more frequently seen in the sciences. Diachronic emergence describes the process of self-organization of complex systems from simpler precursors. Diachronic emergence pertains to the evolution of systems over a period of time, not to the state of the system at a given time. Self-organization, in general, is the process of creating and maintaining internal order; the diachronic use of emergence is focused on the creation of the order, while the synchronic use of emergence is focused on the maintenance of the order.

In the scientific literature, emergence is used in the diachronic sense most often in biology; especially in regard to the origin of life on Earth, and sometimes in regard to Darwinian evolution. All life on Earth today has descended from earlier life (putting aside the issue of synthetic life for the time). Organisms cannot reproduce without metabolism – order generation needs to be coupled to thermodynamically favorable processes. Furthermore, the development of the adult organism involves many feedback mechanisms. On another level, Darwinian evolution appears to be an example of a feedback 'mechanism'[10] for the generation of new order. The cycle of mutation, reproduction and selection is a sort of feedback mechanism (though a relatively abstract sort of mechanism). Individual mutations and small changes in allele

[10] On this account, emergence and mechanism are compatible; nothing in the concept of emergence precludes mechanistic explanation.

frequency are 'fed back' to the system and can become amplified over multiple iterations of the cycle. In this way, the theory of evolution has been able to explain much of the complexity observed in modern earth life.

The origin of life is a more difficult topic of inquiry than the origin of a modern species for many reasons. Some of these reasons are epistemic, we have very little direct evidence about what the first life on Earth was like, and even the conditions on early Earth are rather speculative. Other reasons are conceptual; it seems to take life to make life. We do not know how a replicator can be made without there already being a replicator in existence. Some have speculated that the first replicator arose by chance, which seems unlikely because even the simplest replicator is a rather complex molecule. In this case, it would not be entirely appropriate to say that the first replicator arose by a process of diachronic emergence. In this scenario, the organization did not arise via feedback processes, rather a single chance event would have brought about the order. This is typically the approach taken by proponents of the RNA-world model of the origin of life. However, there are difficulties in this position; RNA is not a very stable molecule, and it has proven challenging to get a self-replicating ribozyme to form by chance. Furthermore, this approach is somewhat contrary to the spirit of scientific inquiry; appealing to a 'statistical miracle' does not give insights to the mechanisms or laws governing the origins of the replicator.

An alternative approach has been to look for a metabolism-first origin of life. This idea has been advanced by Stuart Kauffman, who argues that once certain systems reach a critical level of ordered complexity, they will continue to develop and increase in complexity (Kauffman 1986). This account makes use of the concept of emergence in the diachronic sense. Kauffman and other proponents of the metabolism-first model argue that as chemical reactions on early earth progressed, at some point a feedback loop developed. This then would allow any small changes which makes the primitive metabolism more efficient to be amplified through iterations of the autocatalytic cycle. Each change that speeds up a reaction along the chemical pathway, by virtue of being on the same pathway, increases itself. Those changes which slow or break the cycle eliminate themselves. This model suggest a diachronically emergent mechanism to bootstrap life.

The mind, like life, appears to have originated via diachronically emergent processes. In regard to consciousness, diachronic emergence is pertinent both to the evolutionary origins of consciousness and the development of a conscious person from a non-conscious zygote. As we have already discussed, Darwinian evolution, in general, appears to be a diachronically emergent process. However, in the case of consciousness, there is the additional difficulty in explaining what sort of evolutionary advantage consciousness provides.

Furthermore, the development of each individual brain appears to be diachronically emergent. While it is guided by genetics, the resultant system (the mature brain) contains far more complexity, far more information, than is coded for in the genome. The idea that the brain develops via self-organization has been advanced by Gierer; "only in recent times has it become clear that the de novo generation of spatial order is consistent with known laws and processes of physics, thus reconciling holism and physicalism. Understanding brain evolution requires that networks of gene regulation be related to neural networks, which is a real challenge for systems theory." (Grierer 2002) The human brain contains on the order of 10^{10} neurons with around 10^{13} connections, yet the human genome has only about 10^{9} base pairs, and only a tiny fraction of these play any role in the development of the brain. (Grierer 2002)

Clearly then, the formation of neurons and neural connections must emerge via pattern generation mechanisms. These mechanisms are likely highly sensitive to small changes in the initial conditions, or conditions as the brain develops (this is evidenced by the sensitivity of embryos and fetuses to even small doses of teratogens). This is suggestive of the sorts of feedback mechanisms which can be seen in Darwinian evolution and perhaps the origin of life. Hence, the concept of emergence in the diachronic sense that I advocate could be of use in understanding the development of the mind.

Furthermore, emergentism in regard to the mind can help us avoid both the pitfalls of dualism (which postulates a separate mental substance), and reductive identity theory (the view that mental properties and phenomena are physical, and identical to particular physical structures or processes). Unlike dualism, emergentism requires no special substances. It allows us to treat thoughts, beliefs, desires and other mental phenomena as real, even though they are composed entirely of physical objects (much in the same way that solid objects are real, even though none of the parts, on the atomic level, are solid). And unlike identity theory, we are not committed to the position that only physical systems which are exactly like our own can have mental states. Furthermore, this concept of emergence is distinct from functionalism. Unlike the functionalist, the emergentist can place additional constraints about the internal structure and composition of the system for the system to be regarded as conscious, denying that the causal inputs and outputs are all that matters.

This claim may seem odd, as self-organization and feedback are widely taken to be functional – that they are features of causal inputs and outputs of a system. This brings us to the closely related issues of functional accounts of emergent properties and computational modeling. Both in regard to the study of life and the study of mind, there has been a trend toward a functional analysis. This has gone hand in hand with developments in computer science and computational modeling of complex systems, especially neural networks and artificial life. In particular, there is the currently fashionable idea that replicating and 'evolving' data structures may not only simulate evolution, but actually acquire the emergent properties of being alive and evolving(Lange 1996). However, we must exercise caution when drawing conclusions from such models. Do we treat computer simulations merely as tools to help us understand the phenomena, or as genuine cases of the phenomena itself? If the phenomena in question is a purely functional kind then simulations are genuine examples of the phenomena; the input-output structure of the simulation is identical to that of the phenomenon itself. While there may be functional aspects of emergence (both in the synchronic and diachronic usage), I argue that emergence is not purely functional. Emergent properties are not necessarily functional properties, nor can we always give adequate functional accounts of them.

This last claim, that causally relevant properties cannot always be functionalized, is a radical one. Functionalization has been a powerful tool in the reductivist approach, and the general trend in the literature has been to try to functionalize all apparently emergent properties, so that they may be ontologically reduced;

> "To reduce the gene to the DNA molecule, we must first prime the target property, by giving it a *functional* interpretation – that is, by construing it in terms of the causal work it is to perform. Briefly, the property of being a gene is the property of having some property (or being a mechanism) that performs a certain causal function, namely that of transmitting phenotypic characteristics from parent to offspring. As it turns out, it is the DNA molecule that fills this causal specification ("causal role"), and we have a theory that explains just how the DNA molecule is able to perform this causal work. When all of this is in, we are entitled to the claim that the gene has been reduced to the DNA molecule." (Kim 1999)

As compelling as Kim's argument is, I argue that not all causally relevant properties can be functionalized. Take, for example, the property of being water. The property of being water certainly has causal relevance; it performs causal work, such as dissolving sugar and salt and quenching thirst in humans. In fact, medieval alchemists had an essentially functional concept of water. But, as Putnam's famous Twin Earth thought experiment demonstrates, being water is not a functional property. In this case, the property is a micro-structural one. Twin Earth 'water', composed of XYZ molecules, is not water, despite the fact that it has the same causal powers as water.

Looking at other properties of interest, it seems that while some properties, like the property of being a gene, can be functionalized, many others cannot. Properties of being a certain substance, like water or gold, for instance, may have some causal functions, but the properties themselves are not functional. I believe that attempts to functionalize mental properties are misguided for the same reason. Mental properties play causal roles (my pain from the migraine was indeed what caused me to take the ibuprofen), and may emerge from certain micro-structural features of the brain (firing of C-fibers), but pain is neither of these things; pain is an essentially phenomenal kind. Kripke gives a particularly cogent argument for this:

> "Because although we can say that we pick out heat contingently by the contingent property that it affects us in such and such a way, we cannot similarly say that we pick out pain contingently by the fact that it affects us in such and such a way. On such a picture there would be the brain state, and we pick it out by the contingent fact that it affects us as pain. Now that might be true of the brain state, but it cannot be true of the pain. The experience itself has to be *this experience*, and I cannot say that it is a contingent property of the pain I now have that it is a pain." (Kripke 1971)

Regardless of sameness of micro-structural features, or sameness of causal features, a phenomenon is not a pain if it lacks the phenomenal features of pain, the *qualia* of pain. Similarity microstructure or similarity in causal features may provide us with good evidence that something is a pain, especially when we cannot have access to the essential phenomenal features; this is how we infer that others are in pain. But we should not mistake the effect for the cause, nor the base properties for the emergent property.

The fact that pain is an emergent property, and that it is ontologically irreducible, either to a functional kind or micro-structural kind does not preclude the development of theories to help us predict pain, and explain why something is painful, or why someone is in pain. Pain is not the behavior of wincing or screaming, but the fact that someone is wincing and screaming is good evidence that they are in pain. Likewise, the firing of C-fibers is not pain, but our theories in neuroscience allow us to predict that, for example, a drug which inhibit the C-fibers will function as an analgesic (will reduce pain). Our ability to predict and explain why something is painful does not make the pain any less real, nor does it show that pain is 'nothing but' the firing of C-fibers.

This argument that emergence is not entirely functional, and that many emergent properties are not functional properties, does not, however, show that machines cannot instantiate emergent properties. Machines, even data structures within a computer, instantiate many important, causally relevant properties; properties that are not present at the lower levels of their parts. Furthermore, a machine could in principle be self-organizing, that is it could actively create and maintain internal order. And, as emergence is general in regard to level of analysis, it does not seem problematic to allow for self-organizing data structures which arise from electrical currents in a computer (or what ever other means the information is stored in a Turing machine).

CHAPTER V.

Objections

One of the strongest objections to the concept of emergence is that emergence entails that there are instances of downward causation, and that the concept of downward causation is fundamentally incoherent. This is sometimes referred to as the exclusion argument. This objection is particularly well articulated by Jaegwon Kim in his 1993 paper, "The Nonreductivist's Troubles with Mental Causation." In this paper, he argues that emergentists and other non-reductive physicalists face insurmountable difficulties due to the incoherence of downward causation. Although Kim's argument is made in regard to emergentism, or non-reductive physicalism, of the mind, it can easily be generalized to pertain to emergentism in general (Humphreys 1997). This argument assumes emergentism to be committed to five basic principles: (1) Token Physicalism "All concrete particulars are physical."(Kim 1993) (2) 'Anti-reductionism', that emergent properties are not reducible to physical properties. (3) That emergent properties are physically realized, or supervene on physical properties. (4) Realism – That emergent properties exist and are real properties of objects and events. And (5) Causal significance of the emergent properties – emergent properties are not epiphenomenal (Kim 1993, Humphreys 1997).

The first part of Kim's argument is to show that the emergentist is committed to the existence of downward causation. From premises (1), (4) and (5), it follows that the emergentist is committed to the existence of non-fundamental physical properties (properties above the 0^{th} level) with causal relevance. Next he asks, relative to the level of the causally relevant emergent property instance, are the effect property instances lower-level property instances, same-level property instances, or higher-level property instances? If the effects are lower-level property instances, then we have already established downward causation. If the effects are same-level or higher-level property instances, then Kim uses premise (3) to argue that the only way to cause a supervening property is to bring about its subvenient base, which must be of a lower level than the supervening property. He calls this the Causal Realization Principle: "If a given instance of *S* occurs by being realized by *Q,* then any cause of this instance of *S* must be a cause of this instance of *Q* (and of course any cause of this instance of Q is a cause of this instance of S)."(Kim 1993) If the original effect was the same level as the emergent cause, then this establishes that there must be downward causation, and if the effect is a higher level, then this step is repeated at each level until downward causation is established.

The next part of the argument is to show that downward causation is incoherent. This is because of what Kim calls "The Principle of Causal Inheritance: If M is instantiated on a given occasion by being realized by *P*, then the causal powers of *this instance of M* are identical with (perhaps, a subset of) the causal powers of *P*." (Kim 1993) This principle seems fairly intuitive at first, especially if the emergentist accepts premise (3) that emergent properties are physically realized, or supervene on the physical. From this he argues that the causal powers of the lower-level base *P* preempt *M* as the cause of the effect *P**: "The critical question that motivates the argument is this: If an emergent, *M*, emerges from basal condition *P*, why can't *P* displace *M* as a cause of any putative effect of *M*? Why can't *P* do all the work in explaining why any alleged effect of *M* occurred?" (Kim 1999) Here, Kim argues that the emergentist is in a bind. He cannot say that the emergent property *M* and the base physical property *P* are the same, because the emergentist is committed to premise (2) that the emergent property *M* is not reducible to *P*. And he rejects the idea that the emergent property *M* could be a causal intermediate: "Moreover, it is not possible to view the situation as involving a causal chain from *P* to *P** with *M* as an intermediate causal link. The reason is that the emergence relation from *P* to *M* cannot properly be viewed as casual[11].” (Kim 1999)

This is indeed a strong objection to emergentism. It seems to show that emergence is a untenable position; caught as it were, between the Scylla of reductionism and the Charybdis of substance pluralism (Boogerd et al. 2005). The only way out seems to be to reject the highly plausible Causal Inheritance Principle. Kim ends his article with a challenge to those who reject his conclusion: “I challenge those non-reductivists who would reject this principle to state an alternative principle on just how the causal powers of a realized property are connected with those of its realization base; or to explain, if no such connections are envisaged, the significance of talk of realization.” (Kim 1993)

This objection has been addressed by Paul Humphreys in “How Properties Emerge” and “Emergence, Not Supervenience.” First, the account of emergence proposed by Humphreys differs somewhat from the emergentist position Kim assumes for the argument. Humphreys accepts premises (1)token physicalism, (4) realism in regard to emergent properties, and (5) causal efficacy of emergent properties. Premise (2) anti-reductionism, is somewhat ambiguous; as Searle explains in “Reductionism and the Irreducibility of Consciousness” there are several different senses of the term 'reduction'. It seems that Humphreys would accept (2) in regard to ontological reduction – emergent properties cannot be ontologically reduced to lower level properties – but perhaps Humphreys would agree with Wimsatt and argue that emergence is compatible with what is sometimes called 'reductive explanation.' Humphreys clearly rejects

[11] Here Kim is referring to C. Lloyd Morgan's Emergent Evolution: “We urge that from the nature of the case we can only "enjoy" such psychical correlates of life and matter as arc involved in the whole integral psychical system at our level of mind. With psychical correlates of life at level B only, and of matter at level A only, we can have no direct acquaintance; for we cannot be an amoeba at the one level, or a molecule at the other level, so as to be thus acquainted with the psychical attribute which it alone can "enjoy." It need hardly be added that there is no causal relation of the one attribute to the other” (Morgan 1927)

premise (3). Emergence, on his account is not a special case of realization or supervenience, it is a distinct dependence relation.

Because he accepts premises (1), (4) and (5), Kim's argument would suggest that he is committed to downward causation. However Humphreys argues that he is not because he rejects premise (3), and the Causal Relevance Principle. He maintains that higher level property instances are not always caused by something causing the base property instances. Rather, in many cases higher-level property instances can be directly caused, without all the lower-level property instances actually occurring.

> “Suppose that $P_1^{i+1}(x_1^{i+1})(t'_1)$ causes $P_k^{i+1}(x_k^{i+1})(t'_2)$, where both these instances are at the i+1 level. What we have is that the i-level property instances $P_m^i(x_r^i)(t_1)$ and $P_n^i(x_s^i)(t_1)$ fuse to produce the i+1-level property instance $[P_m^i * P_n^i](x_r^i + x_r^i)(t'_1)$, which is identical with $P_1^{i+1}(x_1^{i+1})(t'_1)$. This i+1-level property instance then causes the second i+1-level property instance $P_k^{i+1}(x_k^{i+1})(t'_2)$. This second i+1 property instance, *if also emergent*, will be identical with, although not result from, a fusion of i-level property instances $[P_r^i * P_s^i](x_u^i + x_v^i)(t'_2)$. But there is no direct causal link from the individual property instances $P_m^i(x_r^i)(t_1)$ and $P_n^i(x_s^i)(t_1)$ to the individual decomposed property instances $P_r^i(x_u^i)(t_3)$ and $P_s^i(x_v^i)(t_3)$.” (Humphreys 1997)

Humphreys also avoids the second part of Kim’s argument by rejecting the Causal Inheritance Principle. As explained above, emergent properties do not supervene on the base properties, nor are they realized by the base properties. While the emergent property is instantiated in a composite whole, many of the relevant causal properties of the parts are no longer being instantiated.

CHAPTER VI.

Conclusions

As I have shown, there is nothing deeply mysterious or inexplicable about emergence. Emergent properties are simply system properties that bestow novel causal powers to the system. While this form of emergence may not rescue the traditional notion of free-will from causal determinism nor bring back the doctrine of vitalism, it is more useful than it may first appear. By emphasizing the context-sensitivity and complex interactions within systems, it helps avoid oversimplified models. Rather than settling for a simpler model at some preferred level of analysis, we should heed Wimsatt's advice and “work back and forth between the ontologies of different levels to check that features crucial to upper level phenomena are not simplified out of existence when modeling it at a lower level.” (Wimsatt 1997)

Furthermore, this concept of emergence can help us avoid misleading 'nothing-but' claims that lead to overlooking important higher level phenomena: that life is nothing but organic chemistry, or that the mind is nothing but neural activity. For instance, some neuroscientists and philosophers of mind claim that 'the mind is nothing-but neural activity,' implying, sometimes explicitly saying, that it does not really exist. This is the basis for eliminativism of the mental, a position which is advocated by the Churchlands. Yet we feel that if there is anything we are sure of it is our conscious experience. This was the key insight in Descartes' *Meditations*, where he determines that the only thing he can be absolutely sure of is his own existence, “*Cogito ergo sum*” “I think therefore I am.” (Descartes 1641) In a way, Descartes was right. We can be certain that we are having a conscious experience, it is immanently self-evident. The fact that we are having a conscious experience proves that conscious experiences exist. What is not self-evident, however, is the nature of the conscious experience. Emergentism allows one to assert without contradiction both that consciousness exists, and that there is nothing mysterious or supernatural about it. I very much agree with Wimsatt's conclusion that “Yes, we are something more than quarks, atoms, molecules, genes, cells, neurons, and utility maximizers. And now we have some means to count the ways.” (Wimsatt 1997)

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