ФИЛОСОФИЯ НАУКИ

EMERGENCE, VARIETIES OF EXPLANATION, AND THE GENERALITY OF LAWS* (part I)

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The principal aim of this paper is to show that a constraint that C.D. Broad imposed on the acceptability of deductions of macroproperties which would show them to be non-emergent, viz. that they use only general laws of nature, is too strong and should be replaced by the weaker condition that the deductions be non-trivial. First, the relevant notion of generality is made more precise. I propose that a law is general iff it is applicable to a diversity of phenomena relative to what I call «domain constitutive properties». In order to substantiate the claim that Broad's constraint is too strong I analyse three examples of explanations of macroproperties from robotics and the life sciences. All of them are non-trivial explanations and should thereby render the explained properties non-emergent. Finally, I briefly indicate three ways in which an explanation may be non-trivial.

Key words: emergence, laws of nature, reductive explanation, macro properties.

The notion of emergence has been with us throughout the 20th century. Its birth was prepared by Mill's distinction between homopathic and heteropathic laws and by Lewes' coining of the term «emergence» [19; 16; 7]. In the minds of Samuel Alexander and Conwy Lloyd Morgan the notion took on shape and received its canonical form in Charlie Dunbar Broad's classic work «The Mind and Its Place in Nature» [2; 7; 18]. Broad conceived of emergence as a means to ground our intuition that there are certain fundamental differences between things in the world, e.g. between living and nonliving things and between mindless and mindful creatures. Broad's question was «Are the apparently different kinds of material objects things irreducibly different?» and reduction or reducibility was, in his eyes, *the* means to show that the differences are only apparent. Although there has been some work on emergence in recent years (e.g. [12; 13; 15; 16; 9; 11]) the treatment of the concept in the hands of Broad remains classical. Modern work on emergence can be either situated in the tradition of Broad (e.g. [16; 4; 5]), in which case some crucial assumptions of Broad's approach are shared, or it stands outside that tradition and tries to characterize the notion of emergence in-

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dependently from the notion of reduction, e.g. by novelty, qualitative difference from lower level properties or fusion of properties (e.g. [8; 13]). By focussing on the tradition which goes back to Broad the aim is to discuss a certain assumption of Broad's which has not been challenged in recent work, but which is crucial for the question of which properties are emergent and which aren't. This is the assumption that a reductive explanation of a macroproperty has to use *general laws of nature*. If a deduction of a macro property could only be had by using rules (regularities) which are *not* general laws of nature then, according to Broad, the macro property would be strongly emergent.

A difference that may strike us more than any other, namely that between a living organism and a non-living thing like a rock which does not move about, does not eat, not develop and not procreate, this difference would be only apparent if it could be shown that the things which make up a living organism, viz. its molecules, which are not alive themselves, behave in such a way that the typical characteristics of life of the whole organism, or of a single cell for that matter, are a necessary consequence of this behaviour.

Actually, Broad imposed an even stronger condition on the relation between the property of the whole and the properties of its parts. The deduction of the macro property had to use only *general* laws of nature. What this condition really amounts to we shall see below.

The aim of this paper is to show that Broad's criterion is too strong because it does more than just preclude trivial deductions of a macro property. It also excludes deductions which we intuitively consider as explanations of an emergent phenomenon, explanations which should render the phenomenon non-emergent in Broad's view. In order to show this three examples of explanations of macro properties are analyzed which differ according to how difficult it is to «see», that is, to be aware of the macro property once you know the rules governing the behaviour of parts of the system in question. I will argue that although the rules which are used in these explanations are not general laws the explanations render the properties to be explained non-emergent. Before that, however, the concept of a general law has to be made more precise. I suggest that a law is general iff, first, it applies to all objects within a domain characterized by what I shall call «domain constitutive properties» and, second, there is a certain kind of diversity inside the domain, viz. a diversity relative to the domain constitutive properties. But first, I would like to say some words about the role of reducibility in the business of showing that apparent differences between things are not what they appear to be.

Apparent differences between things and their reducibility

Why reducibility? Why is the difference between a pebble and a mouse only apparent if reproduction, for example, can be explained by DNA-replication and subsequent chemically triggered processes of morphogenesis? Why is the difference between a *pebble* and a mouse only apparent if the explanation doesn't even mention pebbles? Presumably, the answer to this question has two parts. The first part answers the question why the difference between non-living DNA-molecules and living cells is only apparent. If we can deduce the capacity for reproduction from knowledge about the properties of DNA-molecules and knowledge about how they interact with other chemical components of the cell this capacity is already virtually contained in our knowledge in the same sense in which a surprising theorem of number theory is already contained in our knowledge of the axioms of number theory. Although there is such containment, what does count for us is that we really draw the conclusions and arrive at the theorem or, for that matter, at the capacity for reproduction. As long as we don't «see» how the conclusion follows from our theoretical knowledge we are struck by the impression of a surprising difference. Of course, there still is this difference between single molecules and a cell or an organism, viz. that the latter are alive whereas the former are not, but this difference is not unbridgeable any more as it seemed to be as long as we could not deduce (at least in principle) the characteristics of life from our knowledge of molecular biology.

The second part of answering the question why the difference between pebbles and mice is only apparent is more problematic than the first. The leading idea seems to be that things like pebbles share with DNA-molecules the property of not being alive and that if the difference between DNA-molecules and a cell is only apparent then via some kind of transitivity the difference between arbitrary things that *do not* have the macro property and things which have it is only apparent. That, however, is a non sequitur since not every kind of thing that does *not* have the macro property has the right micro properties which enable deduction of the macro property. So there may be a deductive relationship between being a DNA-molecule (etc., etc.) and being alive without there being such a relationship between being a plutonium molecule and being alive.

The basic mistake in this line of reasoning lies in the fact that the sharing of a negative property is treated like the sharing of a positive one. If we know that two things share the property of life we can infer a lot of things, such as that they need energy (food), that they have parents, that they have cells, metabolism, etc., etc. If one takes a property pertaining either to the cell level or to a global functional level and if this property is sufficiently abstract (like having prey and predators, being adapted to its niche) there is accordingly a high probability that if one of two arbitrary organisms has it the other has it too. The same is not true of the negative property of not being alive. Two things which are not alive could be as different as a proton and a combustion engine or a piece of copper and a radio station. If we know that two things are not alive we cannot infer as much about them as we could if we knew that they were alive. In any case, if deducibility is to be the bridge between micro and macro properties there will be no bridge between pebbles and mice and in this sense this apparent difference will survive even if life can be deduced from DNA-molecules (etc., etc.).

After these preliminary remarks whose point was that you don't need non-deducibility in order to show that certain apparent differences are real I would like to introduce the condition that Broad deemed to be crucial for an acceptable reductive explanation. Before introducing this condition it will be helpful to describe the form of reductive explanations which Broad had in mind.

Broad's concept of reductive explanation

According to Broad an explanation of a macro property is reductive if this property can be deduced by, first, knowledge about the properties of the component parts of the system and, second, composition principles by which these properties can be combined. A simple example of such a composition principle that connects the masses of the parts of a body with the mass of the whole body is addition. What is important in this case is that nothing more than the values of mass of the parts and the composition principle (addition) is needed in order to deduce (compute) the macro property. The reason why nothing more is needed is simply that the property to be deduced and the properties on which the deduction is based are the same, mass in both cases. If the properties of the parts and of the whole are different and if the composition principle is a numerical function which combines values of the part properties in order to yield a specific value for the whole there has to be an additional mapping from this value to the macro property in question. For example, if the result of a calculation concerning a chemical substance is that it is a donor of protons there has to be a connection between being a donor of protons and being an acid if this last property is the one to be deduced. These connections have to be identities or realisations because these are the only relations which do not require a further explanation of why the connections hold (cf. [22]). Would they stand in need of further explanation the deduction would be unsatisfactory precisely because the transition from the computed value for the whole (which is still a value of a property *in micro terms*) to the macro property in question would not be accounted for.

Broad's conviction, at the time he was writing his book in the early twenties, was that already properties of chemical compounds were emergent because the necessary composition principles were lacking. According to Broad, these composition principles had to satisfy a further condition whose function was to prevent a trivialisation of the deduction. If we wanted to deduce that water dissolves salt and we based our deduction of this property on the empirically well confirmed «principle» that a combination of two volumes of hydrogen with one volume of oxygen yields a compound which dissolves salt then we could deduce this property. But in the same manner we could deduce every compound property whatsoever provided that there are the right empirical regularities. It was Broad's belief that in every case of an emergent property there are such regularities but that they were unique and ultimate laws which had no further explanation [7. P. 65]. If these regularities were accepted for the deduction of the macro property and if emergence would amount to non-deducibility *tout court* there would be no emergent properties.

The generality of laws

So, in order to exclude trivial deductions Broad imposed a further condition on composition laws as well as on the laws which describe the behaviour of parts inside wholes, viz. that they should be *general* laws of nature. They should not only cover the special case at hand, e.g. water, but other cases of compounds as well. Now, although the motive for introducing this condition is completely sound the condition itself is much less satisfactory. The basic problem is that the scope of generality is left unspecified. Consider the following quote: «We know perfectly well that the behaviour of a clock can be deduced from the particular arrangement of springs, wheels, pendulum, etc., in it, and from general laws of mechanics and physics which apply as much to material systems which are not clocks» [7. P. 60].

With this characterisation of generality the hypothetical case in which there were a law applying only to two substances, e.g. water and ozone, would be compatible. But intuitively whether a law is applicable in one type of case or in two does not seem to make a crucial difference. There would still be room for lots of unconnected chemical facts, islands which just happen to be there for no other reason than the existence of empirical regularities connecting properties of the elements with properties of compounds. Or, if the laws of mechanics applied only to clocks and planets but to nothing else this fact itself would be curious and would prevent mechanics from being a general discipline. So, in order to be a general law it must not only apply to two, three, for, etc. different kinds of system but to *all* kinds of a certain type. In the case of mechanics to all kinds of material systems, in the case of chemistry to all kinds of chemical compounds. It is important not to specify the scope of generality in a purely negative way, e.g. by some such formulation like «for all kinds of systems which are not x (clocks, water, etc.)» since what is to be unified by a general law is a specific domain of phenomena and not all possible domains.

It might be said that whether a law is general or specific depends on how the domain of application is described [14]. Newton's law of gravitation, one could be tempted to say, is only valid for physical systems with mass and so it is not a general law because it applies to just *one* type of system. The error in this kind of reasoning lies in the fact that one takes the properties which define the domain (things which have mass, things which are chemical compounds) and characterises the objects in the domain by these properties. What one wanted to know before someone came up with a law relating the phenomena of a domain was whether and how the different phenomena *inside* the domain are related. A law which is applicable to every phenomenon in the domain shows how these phenomena are related. So what we need for the generality of laws are *domain constitutive properties* like having mass, being a compound, or being alive and diverse phenomena inside the domain like different chemical substances or different kinds of organisms (1). A composition law or a law describing the behaviour of parts of a system is then general if it applies to every phenomenon in the domain and not only to some phenomena.

But couldn't a domain constitutive property be much more specific? Why shouldn't there be domains for every chemical compound such that we would have general laws which, accidentally, would be true of water or salt only? The answer to these questions is that there have to be diverse phenomena in the domain but that there are none. There is just *one* phenomenon, viz. water or salt. But, one might object, while there is only one phenomenon relative to a chemical description, i.e. a description couched in terms of the combination of chemical elements, there are diverse phenomena relative to other descriptions. For example, when we consider a water molecule being in my refrigerator it is of a different type than a water molecule of your refrigerator if we type-identify water molecules in terms of locations or, assuming that you and I are the owners of these molecules, if we type them by ownership. In the same way we could use very different and very numerous criteria for the individuation of water molecules such as aesthetic, historical, functional, etc. and always end up with a diversity of phenomena inside the domain of H_2O. But this diversity does not correspond to our intuition of how the domain should be structured.

Consider the case where the domain constitutive property is that of being a chemical compound and the diverse phenomena are chemically different compounds such as H_2O, NaCl, NH_3, etc. The relation between the domain constitutive property and the properties of being H_2O etc. is that between a determinable and its determinates. A property P_{det} is a determinate of another property P_{deb} iff it is a specification of P_{deb}, if it is P_{deb} but in a specific way. Crimson is a determinate of Red because it *is* red, but a specific shade of red. Red is a determinate of Colour because Red *is* a colour, but a specific colour. Red is not a determinate of Sound because it is not a specific sound. It is no sound at all. If a property is a determinate of another property then if something has the first property it *necessarily* has the second. If something is crimson it cannot be some other colour but red and it must be coloured. The converse, however, does not hold. If something is red it does not *have* to be crimson, it can also be purple or any other shade of red.

Now, the property of being H_2O is just a specification of being a chemical compound and the terms «chemical compound» and «H_2O» belong to the same theoretical discourse, viz. chemical discourse or chemistry. The same is not true of the properties of being a water molecule and being in my refrigerator. These properties are not related as determinables and determinates and the terms do not belong to a single discourse or discipline. A determinate necessitates its determinables. Being in my refrigerator, however, does not necessitate being water since something can be in my refrigerator without being water. It follows that being water and being in my refrigerator are not related as determinables and determinates. The absence of properties which distinguish diverse phenomena, i.e. different determinate properties, *and* which belong to the same discourse shows that being a H_2O molecule cannot plausibly be a domain constitutive property and so the objection that arbitrary descriptions may distinguish between different phenomena in the putative domain of H_2O can be rejected. The positive effect of the objection, however, is that it leads to a further specification of the relation between domain constitutive properties and properties by which the phenomena inside the domain are individuated. The domain constitutive properties and the properties which mark out the different phenomena in the domain must be related as determinable and determinates and, correspondingly, the terms which express these properties must belong to the same discourse. According to this analysis composition laws and laws describing the behaviour of parts are general if they apply to all objects of a domain which is characterized by some domain constitutive properties and which contains different phenomena. The differences between these phenomena have to be such that the properties which determine these differences are related to the domain constitutive properties as determinates and determinables.

If a composition law is general in this sense and a given macro property can be deduced this property is thereby shown not to be emergent.

A comparison with Achinstein's account of generality

This characterization of the generality of laws is somewhat different from the conditions Achinstein gave in his book on law and explanation [1]. There he distinguished five criteria of generality four of which would make the composition laws that Broad wanted to exclude into general laws.

According to the first criterion laws are syntactically general «in the sense that they are formulated beginning with a universal term 'All' or 'No' followed by a subject term» [Ibid. P. 25]. This condition is not only satisfied by what we intuitively take to be laws but also by accidental generalizations like «All coins in my pocket are dimes».

The second criterion (2) requires that the universals expressed in laws are unrestricted. This criterion seems to reduce to the requirement that laws be counterfactual supporting, for with respect to Galilei's law of falling bodies Achinstein writes: «For Galileo's law to be true it is necessary that all bodies... whether or not they are or ever will be unsupported, be such that if they were unsupported near the surface of the earth they would fall with uniform acceleration» [Ibid. P. 27]. A proposition expresses an unrestricted universal if it warrants subjunctive conditionals saying that so and so would happen if such and such were the case. The proposition «All coins in my pocket are dimes» does not warrant such a conditional because the fact that they are in my pocket does not make them into dimes. A proposition like «If this nickle were in my pocket it would be a dime» is clearly not warranted by the generalization about dimes. Thus accidental generalizations are excluded from being laws but composition laws connecting properties of parts with properties of wholes would not be excluded. Suppose we have a composition law which stetes that every stable combination of two hydrogen atoms and one oxygen atom yields a liquid under normal temperatures if there is a big number of such molecules. This regularity is counterfactual supporting. If a big number of marbles were stable configurations of H_2O then *they* would form a liquid. So, this criterion does not distinguish either between genuine general laws and those laws which Broad wanted to refuse as premisses in the deduction of a certain macro property.

The third criterion is equally unsuited to this task. It claims that «what it [the law] says about a subject is supposed to hold for every particular sample or instance» [Ibid.]. For example, if the subject of the law are gases then the law is supposed to apply to any sample of a gas. By contrast, the generalization «All gases are studied by the chemist» is not supposed to be true of every *sample* of gases but only of every *type* of gas. However, composition laws combining the properties of parts with the properties of a whole can be general in this respect without being general in the sense required by Broad.

In order to decide whether a general law must not mention specific objects, places, or times Achinstein introduces a fourth criterion. Accepting the intuition that Kepler's laws are genuine laws this criterion is designed to do justice to that intuition while at the same time it prevents *some* propositions referring to specific objects, places, or times, from being general laws. The gist of the criterion (its exact formulation is somewhat complex) is that a law may mention specific objects, etc. if at the time it was stated no generalization of it was known that did *not* refer to specific objects, etc. Though this criterion seems to be problematic since it introduces epistemological concepts I will not dwell on it simply because the composition laws in question do not mention any specific objects, etc.

Whereas the preceding criteria cannot be used in order to deny generality to specific composition laws the following criterion might be so used. For a law to be general, according to this criterion, is for its subject to be general. The generality of a subject, in turn, is a relative notion. A subject S' is more general than S if everything which is S is S' but not conversely. For example, the property of being a body is more general than the property of being a planet or a canon ball. Likewise, the property of being a body in a certain gravitational field is more general than the property of being a canon ball and less general than being a body without further specification.

Now the question is this: At which level of abstraction the subject has to be described in order for the description to qualify as a general law? Achinstein's answer is partly intuitive and partly in terms of a clearcut criterion. The intuitive part simply consists in an enumeration of subjects: «...bodies (Newton's first law), thermodynamic systems (first law of thermodynamics), electrolytes (Faraday's first law), and gases (Gay-Lussac's law)...» [Ibid. P. 25]. These subjects are contrasted with projectiles, mixtures of ice and water, copper sulphate solutions, and hydrogen. Analysis and explanation of more particular regularities constitutes the formal part, that is, if a regularity can be analysed and explained by a more general proposition this proposition will count as a law whereas the explained regularity will not.

Apart from the problem that not every generalization which can be explained by something more general thereby ceases to be a law as is shown by the explanation of Kepler's laws by those of Newton, neither part does help very much with our question. The first because we just want to know why it is bodies, etc. which are the proper subjects of laws, the second because it does not preclude arbitrary intermediate levels of abstraction.

But Achinstein proposes a further criterion for the generality of a subject which is relative to a given science or field of inquiry. Every science is concerned with certain properties of its subject matter. Thermodynamics, for example, deals with pressure, volume, temperature, etc. The subjects of laws in these fields are more general than other subjects which have the same properties. The subjects of thermodynamic laws are thermodynamic systems and these are more general than mixtures of ice and water, for example. Although Achinstein doesn't say so explicitly the criterion seems to require that a subject of a law should be the *most* general subject of a scientific field of inquiry.

Now this criterion comes very close to the criterion of a domain constitutive property. Being a thermodynamic system would be a constitutive property in the domain of thermodynamics while having mass would be domain constitutive for mechanics. The difference between Achinstein's criterion and my own is only that his makes use of the notion of generality which it is supposed to analyse while the criterion of a domain constitutive property does not make such a use. What about the second part of my criterion of generality, viz. the diversity of phenomena inside a given domain and the relation between determinable and determinate properties? There is nothing in Achinstein's account which corresponds to it. But we have seen that it is necessary in order to preclude generalizations about single phenomena such as specific chemical compounds from being general laws, We need this second part because otherwise we could say that the domain in question would be a specific subject such as H_2O and the law would be general insofar it applies to all samples of water. But there is no *chemical* diversity in the H_2O domain and this is the reason why a generalization about H_2O is not a general law of nature.

This comparison between Achinstein's criteria of generality and the criterion of domain constitutive properties has the result that the sense of generality which is relevant to Broad's talk of general laws is better captured by the latter criterion. Four of Achinstein's criteria are not concerned with Broad's sense of generality and while the last is on the right track it is incomplete since it lacks the requirement that the phenomena inside the domain be diverse with respect to the specific field of inquiry.

NOTES

(1) My proposal that general laws presuppose domain constitutive properties and properties which are determinates relative to those *and* which mark different phenomena in a domain is, of course, merely a first pass. In order to assess its force of systematization various laws which are accepted as general laws of nature in various disciplines would have to be investigated. I can't even begin to undertake that work here. Instead I would like to note that if we take mass to be a domain constitutive property in physics at first sight it seems that there are no determinate properties which carve up the domain. There is nothing which corresponds to the different compounds in chemistry or to the different species in biology. This is not to say that there are no determinate properties. There are, but they are purely quantitative. They are the different values of mass. It would be interesting to know if this difference between quantitative and qualitative determinate properties has any serious implications for my proposal. But this question goes beyond the present paper.

(2) What I mention as Achinstein's second criterion is actually his third. Likewise for the third and fourth criteria which come at the fourth and fifth position in Achinstein. The reason for this modification is that I want to treat together all those criteria which do *not* distinguish between general and non-general laws in Broad's sense.

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ЭМЕРДЖЕНТНОСТЬ, МНОГООБРАЗИЕ ОБЪЯСНЕНИЙ И ВСЕОБЩНОСТЬ ЗАКОНОВ (часть I)

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Статья посвящена вопросу об условиях правомерного применения понятия эмерджентности к тем или иным качествам макромира. Главная цель статьи — показать, что введенное Ч.Д. Броудом ограничение на приемлемость дедукций макрокачеств, призванных показать, что макрокачества не являются эмерджентными, является слишком строгим и должно быть заменено более мягким, согласно которому эти дедукции должны быть нетривиальными. Во-первых, следует уточнить применяемое в этом случае понятие всеобщности. По мнению автора, закон является всеобщим, если и только если он применим к многообразию явлений в отношении того, что автор обозначает как «конститутивные свойства данной области» явлений. Для обоснования тезиса о чрезмерной строгости ограничений Броуда в статье анализируется три примера объяснения макрокачеств, взятые из области робототехники и биологических наук. Как показано в статье, все объяснения, приведенные в качестве примеров, нетривиальны, а, следовательно, объясняемые с их помощью качества не являются эмерджентными. В заключение кратко определяются три основные типа нетривиальных объяснений.

Ключевые слова: эмерджентность, законы природы, редуктивное объяснение, макрокачества.