Holism and reductionism in biology and ecology

Looijen, Richard

CHAPTER 5
EMERGENCE, REDUCTION AND CO-OPERATING RESEARCH PROGRAMMES

5.1 Introduction

In this chapter I will resolve the first of the alleged contradistinctions between holism and reductionism in biology, to wit the one between the emergence thesis and the reduction thesis. I will argue that the emergence thesis, when interpreted as an empirical claim about relations between properties of wholes and properties of their component parts, is a very plausible and universal thesis, which is, however, in no way contradictory to the reduction thesis. I will do so by discussing properties of various kinds of wholes, which on the ground of this empirical thesis can be called emergent, but can nevertheless be explained in terms of some micro-theory about the component parts and suitable bridge principles in the form of aggregation and in particular correlation hypotheses. This implies that the emergence thesis, in its empirical form, can be considered a valid *ontological* thesis (within the confines of epistemological verificationism) but that the ’in principle’ irreducibility claim which is coupled to it by most holists, must be abandoned.

On this finding, I will develop a new definition of emergence which on the one hand accounts for its original meaning, as expressed by the familiar slogan ’the whole is more than the sum of its parts’, but which on the other hand accounts for the possibility that emergent properties can be explained reductively. This definition expresses emergence in terms of the steps aggregation, correlation and/or identification which may occur in a (heterogeneous) micro-reduction (see chapter 3).

Eventually, I will even arrive at the following remarkable conclusion: if there were no emergence, there would be no (micro-)reductions either! This conclusion links up seamlessly with the conclusion of chapter 4 that if we are dealing with only an ontological identity, there is no way in which we can talk of a micro-reduction and, hence, that if we can speak of a micro-reduction, we cannot be dealing with only an ontological identity. Actually, this means that emergence can be considered the opposite of ontological identity.

Finally, considering this relationship between emergence and reduction and considering the ingredients required for successful heterogeneous micro-reductions (viz. (1) macro-laws or theories, (2) micro-theories, and (3) suitable bridge principles), I will develop my thesis about the mutual dependence of holistic and reductionistic research programmes.

5.2 The doctrine of emergence
5.2.1 The whole is more than the sum of its parts

There are several different versions, or components, of the doctrine of emergence. Firstly, there are empirical (or ontological) claims and epistemological claims. Secondly, there are evolutionary claims and what for ease of exposition I will call ’contemporary’ claims. I will consider each of them.

According to one of the earlier formulations of the doctrine, emergence is "the theory that 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, p. 59; see also Thorpe 1974, p. 110). Because of the final addition, "and of their proportions and arrangements in this whole", this a far-reaching statement, making emergence into a practically mysterious, inexplicable phenomenon. For that reason, it probably has few if any adherents today. A common present-day opinion is rather that emergence at the level of the whole is the result of the specific connections and interactions between the component parts (for example Simon 1962; Bunge 1977; Pluhar 1978; Blitz 1992; Kim 1996). A common opinion in ecology, for instance, is that emergent properties of communities are the result of interactions between the component species (for example Begon et al. 1986, p. 589; see also chapters 8 and 9). It is not surprising, therefore, that one of the leading emergentists (holists) in biology today, Ernst Mayr, states that "Systems almost always have the peculiarity that the characteristics of the whole cannot (even in theory) be deduced from the most complete knowledge of the components, taken separately or in other partial combinations. This appearance of new characteristics in wholes has been designated as emergence" (Mayr 1982, p. 63; see also his 1988, p. 15). Thus, though obviously inspired by Broad, Mayr leaves his addition "and of their proportions and arrangements in this whole" out.

Nevertheless, Mayr states that "the units at higher hierarchical levels are more than the sum of their parts and, hence, that a dissection into parts always leaves an unresolved residue - in other words, that explanatory reduction is unsuccessful" (Mayr 1982, p. 66). He even goes so far as to claim that "attempts at a "reduction" of purely biological phenomena or concepts to laws of the physical sciences has rarely, if ever, led to any advance in our understanding. Reduction is at best a vacuous, but more often a thoroughly misleading and futile, approach. This futility is particularly well illustrated by the phenomenon of emergence" (p. 63). Therefore, "[holists] stress the autonomous problems and theories of each level and ultimately the autonomy of biology as a whole" (p. 66).

5.2.2 Emergent evolution

For a long time the doctrine of emergence has been considered to apply especially, or even exclusively, to complex biological wholes, to such complex phenomena as ’life’, ’mind’ and ’consciousness’, and to epiphenomenal properties such as colour, sound, smell and taste (Lewes 1874-75; Broad 1925; Pluhar 1978; Mayr 1982, 1988; Blitz 1992; Kim 1996). The doctrine "has often been evoked in attempts to explain such difficult phenomena as life, mind and consciousness" (Mayr 1982, p. 63). Mayr himself states, however, that "actually, emergence is equally characteristic of inorganic systems". He cites an example of T.H. Huxley (1868), who claimed that the specific properties of water, its ’aquosity’, cannot be deduced from our understanding of the properties of hydrogen and oxygen (see also Broad 1925, who uses the same example). "Such emergence is quite universal", says Mayr and he approvingly quotes Popper’s (1974a, p. 281) statement that "We live in a world of emergent novelty".

With this quote Mayr shows his affiliation with an evolutionary version of the doctrine of emergence known as the theory of *emergent evolution* (Morgan 1923, 1933; Lovejoy 1927, 1936; Mayr 1960; see also Dobzhansky 1974; Blitz 1992). This theory is actually a phenomenological (descriptive) evolutionary theory, in which the process of evolution on earth, from the forming of the first elements to the appearance of biological species and the emergence of mind and consciousness, is seen as a creative process, called ’creative evolution’, and in which this process is being expressed in terms of the forming of new, ever more complex, entities out of older, more simple ones. Each new entity is thereby seen as an ’emergent novelty’ having new, emergent properties which the older entities did not yet possess. The theory is considered to apply not only to biological evolution but also to the (supposedly) preceding chemical evolution (Mayr 1960; Ayala 1976; see also, apart from the doctrine of emergence, Schaffner 1969b). The coming into being of 'life' and 'mind' are seen as only two 'links', be it of course highly significant ones, in this "Great chain of being" (Lovejoy 1936).

It should be noticed that this evolutionary version of emergentism is actually independent of, though very well compatible with, the 'contemporary' version. That is to say, the theory that in the course of evolution ever more complex entities (wholes) with emergent properties have developed from simpler entities (parts), which did not yet possess these properties, is well compatible with, though independent from, the theory that entities of higher levels of organization (wholes) have, at this (or any particular) moment, emergent properties which their component parts do not possess, neither separately nor in other partial combinations. Bunge (1977) has provided a set-theoretical explication of the concepts 'emergent' and 'novelty' in relation to hierarchical levels of organization which in my view illustrates this point very well. Also, Mayr (1982, 1988) makes no distinction between the evolutionary and the 'contemporary' versions of the doctrine, but is a fervent supporter of both (Mayr 1960). Therefore, as long as there is no reason or need for it, I will not distinguish between the two versions, but unite them both under the claim that a whole has emergent properties which its component parts do not possess, neither separately nor in other partial combinations (that is, other combinations than the one in which they appear in the whole). It may be noted also that the contemporary version follows more or less from the evolutionary version: if the complex entities of higher levels (wholes) have developed in the course of evolution from simpler entities of lower levels (parts) and if the newer entities have emergent properties, which the older ones did not have, then it follows that the complex wholes which we presently distinguish have emergent properties not possessed by the parts of which they are composed. There is no difference between the 'emergent' properties of, say, H_2O molecules which came into existence in the course of evolution through the interaction of two hydrogen atoms and an oxygen atom and the 'emergent' properties of H_2O molecules which are presently composed of two hydrogen atoms and an oxygen atom.

5.2.3 Empirical and epistemological claims

Nagel (1982) points out that the theory of emergent evolution should be distinguished from the emergence thesis as a doctrine about the unpredictability of properties at higher levels of organization in hierarchical systems. While the former is primarily an empirical issue, the latter is primarily an epistemological issue. "Accordingly, the question whether any properties are "emergents" in the sense of being temporally novel is a problem of a different order than the issue whether any properties are "emergents" in the sense of being unpredictable. The latter is an issue largely though not exclusively concerned with the *logical relations* between statements; the former is primarily a question that can be settled only by empirical *historical* inquiry" (Nagel 1982, p. 375; emphasis in the original).

Of course, the same applies to the contemporary version of the doctrine: the claim that a whole has emergent properties not possessed by its component parts, is an empirical claim which should be distinguished from the epistemological claim that a whole has emergent properties in the sense of being unpredictable from, or irreducible to, a micro-theory about its component parts and auxiliary hypotheses.

Assuming the compatibility of the evolutionary and the contemporary version, this actually means that we can make a distinction between two theses of the doctrine of emergence. *Thesis 1* states: the whole is more than the sum of its parts, that is, a whole has emergent properties which its component parts do not possess, neither separately nor in other partial combinations. *Thesis 2* states: the emergent properties of wholes cannot be deduced from, or reduced to, "the most complete knowledge of", that is, micro-theories and auxiliary hypotheses about, their component parts (see the quotes taken from Broad and Mayr in 5.2.1).

Because of the second thesis, the term ’emergent’ has received the additional meaning of ’being irreducible’. It is probably for this reason, because of such far-reaching claims as those of Broad and Mayr, that the doctrine of emergence has become so unpopular amongst reductionists. By adding the irreducibility claim to it, the emergence thesis has received the status of a metaphysical dogma. It has made emergence into a mysterious phenomenon which cannot be explained and must therefore be either accepted on faith (holists) or rejected on account of its inexplicability (reductionists). To many reductionists, the irreducibility claim has been a reason to put emergentism on a par with vitalism and to condemn it without further consideration to the waste-basket.

In the following sections, I will show that there are very good reasons to accept the first, empirical, thesis of emergentism (thesis 1) but to reject the second, epistemological one (thesis 2). This not only bereaves the contradistinction, in this respect, between holism and reductionism of its basis, but also opens the way to co-operation of holistic and reductionistic research programmes.

5.3 Emergence and reduction: a contradiction?

5.3.1 Emergent properties

On the ground of thesis 1 above, it is not difficult to find examples of emergent properties, not only in biology but also in physics and chemistry.

To start with the example provided by Huxley (1868; cited in Mayr 1982, p. 63): the properties of water, its ’aquosity’ (liquidity, transparency), can indeed be called emergent with respect to the component hydrogen and oxygen atoms, because these parts do not possess them, neither separately nor in other partial combinations. However, the example is even more interesting, because it actually involves three levels of organization, viz. the level of water, the level of H_2O molecules, and the level of hydrogen and oxygen atoms. On both higher levels, we can speak of emergent properties with respect to the next lower level. As I have argued in chapter 4, water has properties which H_2O molecules do not possess (to which we can now add: neither separately nor in other partial combinations) and in order to arrive from the level of H_2O molecules at the level of water we need to aggregate over large numbers of these molecules and we need a correlation hypothesis about interactions between these molecules under certain temperature conditions. And H_2O molecules in turn have properties not possessed by their component hydrogen and oxygen atoms, such as the ability under certain temperature conditions to interact with one another to form water and under different conditions to interact with one another to form ice or water vapour. Thus, at both higher levels we can speak of emergent properties.

The example is a special case of the more general example of the chemical affinity of molecules. This too can be called an emergent property, viz. of wholes of atomic nuclei and the electrons moving around them, which their component parts do not possess, neither separately nor in other partial combinations. For each type of molecule has its own specific chemical affinity, the ability to react or not to react with other types of molecules. And for each type of molecule this can be called an emergent property, because their component parts do not possess them, neither separately nor in other partial combinations. Put differently, it is only in the specific combination in which the parts occur in the whole that the whole molecule exhibits the emergent properties it does, that is, has the specific chemical affinity it has.

And what applies to molecules applies of course also to macro-molecules (a distinction which is vague anyway). Each type of macro-molecule has its own specific chemical properties which its component (sub-)molecules do not possess (neither separately nor ... etcetera). One may think of, for instance, the catalytic properties of enzymes and certain other proteins. These can be called emergent properties because their component amino-acids do not possess them, neither separately nor in other partial combinations. In the next chapter I will deal extensively with an example of this, to wit the allosteric properties of hemoglobin molecules.

Another example is provided by Bunge (1977) in the form of a length of copper wire which has certain bulk properties such as high electrical conductivity and brilliance. These too can be called emergent properties, since they are not possessed by the constituent copper atoms (neither ... etcetera). The same applies of course to properties of other metals (the example of gold as a collection of Au atoms mentioned by Causey; see the former chapter), as well as to properties of ’other partial combinations’, such as alloys. Each of these substances or compounds has its own specific properties, which their constituent parts do not possess (and which distinguishes each of them from other partial combinations).

And what applies to metals, applies of course also to other substances. A nice example in this connection is the paradox of Eddington’s desk. Eddington, a famous atomic physicist, wondered how on the one side he was able to write on his desk while on the other side he ’knew’ that the thing consisted of atomic nuclei and electrons moving around them. The paradox can be reduced to the emergent properties of desks, in particular the property of not yielding to the pressure of the writer (that is, their solidness or rigidity).

A final example I will provide is the temperature of gases. This too can be called an emergent property, because the constituent molecules have only such properties as mass, velocity and kinetic energy. As argued in the former chapter, even for one who accepts the ontological identification of temperature and mean kinetic energy, mean kinetic energy is a complex aggregate concept and not a property of individual molecules. In other words, in order to arrive from the kinetic energy of its molecules at the temperature of a gas we need, besides the identification hypothesis, a complex, non-trivial aggregation step and this step guarantees that ’the whole is more than the simple sum of its parts’. The same holds for the macroscopic pressure of gases. For even for one who accepts the ontological identity of the macroscopic pressure of gases and the kinetic pressure of their molecules, kinetic pressure is not a property of individual molecules, but a complex, aggregate concept at the level of large numbers of molecules. Therefore, macroscopic pressure too can be called an emergent property of gases.

In short, the phenomenon of emergence is not restricted to complex biological wholes, but already occurs at even the simplest physico-chemical levels of organization. But if even on these simple levels we can find so many emergent properties, it is of course not surprising that the number only increases with the increasing complexity of wholes at higher biological levels. Assuming the theories of the Big Bang and of chemical and biological evolution we might indeed say, with Popper and Mayr, that we live in a world of 'emergent novelty'. If life, or the complex of properties, processes and phenomena we call life, has indeed developed from inorganic matter, it is almost by definition emergent. And if mind, or the complex of impressions, thoughts, emotions, will and intentionality we call mind, is indeed in some way related to systems of neurons, it is undoubtedly emergent, since, as we assume, individual neurons do not possess this 'property'.

5.3.2 Emergence: a trivial thesis?

At this point, one might counter that I've done violence to the emergence thesis by making it so universal that it has actually become a rather trivial, or even an extremely trivial, thesis. Apart from the fact, however, that I have made its domain as universal as that of the theory of emergent evolution, the thesis may indeed seem trivial. If it is indeed the case that each whole, whether it be a H_2O molecule, a gas, enzyme, desk, tree, bird or human being, has new, emergent properties with respect to its component parts, the emergence thesis may boil down to the trivial statement that there just happen to be different things in this world and that we recognize each thing (or type of thing) on the basis of its own, unique, emergent properties. What other reason than the existence of such properties could we possibly have for calling the one thing 'A' and the other 'B'?

This reading of the (contemporary version of the) emergence thesis would be in line with a remark made by Nagel (1982) regarding the theory of emergent evolution. Nagel notes that if this theory is read as an empirical claim about qualitative changes of things associated with spatial redistributions of things (where one might think of redistributions of sub-atomic particles in atoms, atoms in molecules, molecules in macro-molecules, etcetera), "so that spatial changes are *ipso facto* also alterations of the "properties" of the things redistributed", then "the doctrine of emergence barely escapes collapse into the trivial thesis that things change" (Nagel 1982, p. 376).

Thus, when we put the contemporary and evolutionary versions of the doctrine next to each other, we appear to be dealing with the following two 'trivialities': (1) there are different things; and (2) things change. One may find this, along with Nagel, trivial, in my view, however, it is not trivial at all! For after all, the existence of the diversity of things, inorganic as well as organic, and particularly the development of the one out of the other ('something' out of 'nothing'; 'order' out of 'chaos') is actually still one of the greatest scientific and philosophical puzzles. It is one thing to assume the phenomenological theories of chemical and biological evolution, to explain them is quite another thing. The details of these processes are still to a large extent unknown. Although today of course we also have an explanatory theory at our disposal (the theory of natural selection supplemented with modern population genetics) to explain these processes in principle, the theory's chief problem remains that the history of these processes is largely inaccessible to empirical research.

In other words, the above 'trivialities' actually boil down to the grand old questions: how did the diversity of natural things come into being and how, if at all, can we explain the coming into being of things at higher levels of organization in terms of theories about lower levels? That is to say, the 'trivialities' actually point to nothing but the reduction problem, or, better, the range of reduction problems, in science.

5.3.3 Reduction of emergent ’properties’[37]

Thus, in my view the emergence thesis is a valid, non-trivial and universal empirical thesis about the occurrence of new properties at each higher level of organization. However, acceptance of the universal domain of the thesis (thesis 1 above) implicates that the irreducibility claim (thesis 2), which is coupled to the thesis by most holists (emergentists), is untenable! For many of the properties of wholes, which may now be justly called emergent, have been proved to be explainable in terms of micro-theories about their components parts.

The ’aquosity’ or fluidity of water cannot be deduced from the properties of individual hydrogen and oxygen atoms, but it can be deduced from their interactions into H_2O molecules and from the interactions between large numbers of H_2O molecules under certain temperature conditions. All one needs for this is the theory of chemical bonding, supplemented by the suitable bridge principles in the form of correlation and identification hypotheses.

More generally, the chemical affinity of molecules can be explained in terms of the theory of chemical bonding and this theory can be reduced to quantum chemistry (Zandvoort 1986b). And as a special case, the catalytic properties of enzymes can also be explained in terms of this theory, supplemented by correlation hypotheses about interactions between these enzymes, their substrate and certain inhibitor molecules. As mentioned, I will discuss an example of this in chapter 6.

The emergent properties of a length of copper wire can be "explained by solid-state physics in terms of the copper crystal lattice and the electrons wandering through it. In a sense then the physics of copper bodies has been reduced to quantum mechanics, the basis of solid-state physics" (Bunge 1977, p. R79). A similar reduction applies to the emergent properties of all other solid bodies (macroscopic objects), such as Eddington’s desk.

Finally, as we have seen in chapter 3, the ideal gas law can be reduced to the kinetic gas theory with the help of, first, a hypothesis in which one aggregates in a non-trivial way from the kinetic energy of individual molecules to their mean kinetic energy, second, a hypothesis relating mean kinetic energy to temperature, and third, a hypothesis relating kinetic pressure to macroscopic pressure.

In biology too, there are innumerable examples of reductive explanations of emergent properties, such as the many physiological explanations of life functions of organisms and the many genetic explanations of phenotypical traits of organisms. The enormous growth of biochemistry and molecular biology in the past decennia is of course characteristic in this respect, as are the more recent developments of molecular genetics and particularly, whether one likes it or not, of gene technology.

Although these examples do not preclude the possibility that there are emergent properties which cannot (or cannot yet; see below) be explained in terms of micro-theories, they do indicate that the irreducibility claim of the doctrine of emergence is untenable.

[37] I have put the term properties between parentheses, because it is not properties that are being reduced but predicates (the conceptual representations of properties; see Mahner & Bunge 1997, chapter 1). See chapters 3 and 4 and see below in the main text.

5.4 Ontological and epistemological aspects of emergence and reduction

We may conclude, then, that the empirical component of the doctrine of emergence (thesis 1) is a valid, universal thesis, which is, however, not contradictory to the reduction thesis. Two points are of the greatest interest, however. Firstly, it is important to note that explanations of emergent properties generally require, in addition to a micro-theory, at least one but more often several auxiliary hypotheses in the form of aggregation and transformation rules (correlation and/or identification hypotheses). Secondly, it is of even greater importance that, as argued extensively in chapter 4, it is not properties or things that are being reduced, but *representations* (concepts) of properties or things. I will elucidate both points.

5.4.1 Emergence versus ontological identity

In chapter 3 I have noticed, following Kuipers (1990), that an explanation is also called a reduction if at least one of the steps approximation, aggregation or identification occur. I have also noticed that there are no known examples of law or theory reduction in which only an identification step occurs, and that in all known cases of identificatory reduction the identification step is always accompanied or preceded by another step. In heterogeneous micro-reductions this is always an aggregation step. In the above mentioned examples of reductive explanations of emergent properties one may have noticed that they also always seem to require aggregation, correlation and/or identification hypotheses (in addition to the reducing micro-theory). Especially correlation hypotheses about interactions between parts generally seem to play an important role.

The major conclusion of chapter 4 was, moreover, that if concept reductions are to involve (only) identification hypotheses they cannot be micro-reductions. It follows that if we are dealing with (heterogeneous) micro-reductions, they must involve more than just identification hypotheses.

I think we can now link these conclusions to the empirical (ontological) thesis of emergentism, that a whole has emergent properties which the component parts do not possess, neither separately nor in other partial combinations. That is, we can now explicate the claim that the whole is more than the sum of its parts in the sense that a whole has emergent properties which its component parts do not possess, neither separately (no ontological identity) nor when simply added together (no trivial aggregation) nor in other partial combinations (correlations with other entities). It is only in the specific combination in which the parts occur in the whole, resulting from, we can now say, their specific mutual interactions (correlation), that the emergent properties of the whole appear. In other words, in order to arrive from the properties of the parts at the emergent properties of the whole we generally need non-trivial aggregation and/or correlation hypotheses (possibly in addition to identification hypotheses). Nagel too notices that this fact, that suitable bridge principles must be added to a reducing theory in order for a reduction to succeed (his condition of connectability), "illustrates what is perhaps the central thesis of the doctrine of emergence" (Nagel 1982, p. 372).

Thus we can draw the conclusion that it is only when an identification hypothesis (and possibly a trivial aggregation hypothesis) is the only bridge principle used in a reduction, that we *cannot* talk of emergence at the level of the whole, and, hence, that we can talk of emergence at the level of the whole if in a reduction more than just an identification hypothesis (and possibly a trivial aggregation hypothesis) is being used. On these grounds, it is even very difficult to find examples of properties of wholes that are not emergent. The only example I can think of is the mass of a whole: this is exactly equal (ontologically identical) to the sum of the masses of its parts. In all other cases, in which there is more than simple addition and identification, we can talk of emergence at the level of the whole. In other words, the conclusion we can draw is that emergence is the opposite of ontological identity.

A perhaps even more interesting conclusion, that follows from the above considerations, is that if there were no emergence, there would be no (micro-)reductions! For if there were only ontological identities in this world (that is, if there weren't any different things or attributes), there would be no reason for us to even think of reductions. Consequently, there must be more than just ontological identities to even bring the question of reduction in sight.

All of this means that we can define the concept of emergence also in epistemological terms (in addition to the basic, ontological definition). This definition should (a) account for the original empirical content of the concept (thesis 1 above); but also (b) account for the fact that many emergent properties have been proved to be explainable in terms of micro-theories and bridge principles; and (c) not preclude the possibility that there are emergent properties which are not (yet) thus explainable. The definition satisfying these conditions is an extended and amended version of the one provided by Pluhar (1978).

According to Pluhar (1978, p. 286), a property may be called emergent "if and only if its instantiation is either (1) (..) irreducible to micro-theory or (2) reducible to micro-theory in conjunction with merely correlatory bridge laws". Apart from the fact that in my view the word "merely" in the second disjunct of this definition is rather misplaced (stemming from a time when identification hypotheses were considered of more interest in reductions than correlations), Pluhar intends to indicate with this second disjunct that a property cannot be called emergent if it (or its instantiation) is reducible to a micro-theory in conjunction with an identification hypothesis.

As to the first disjunct, it should be noticed that irreducibility may be a temporary matter, since the question whether or not a reduction is successful depends on the theories and bridge principles available at a certain time. It is very well possible that some property may not be explainable in terms of some micro-theory T1 and bridge principles BPx at time t1, but is explainable in terms of another micro-theory T2 and bridge principles BPy at time t2. Consider, for instance, that thermodynamics was not reducible to the mechanics of around 1700, but meanwhile has been reduced to modern statistical mechanics (see also Nagel 1982, pp. 343-5, 361-4).

Furthermore, Pluhar's definition is in need of amendment in the sense that it doesn't take into account the aggregation step which always occurs in micro-reductions. As mentioned before, this step may consist of a simple, trivial addition or a more complicated, non-trivial aggregation. Now when the transformation step in a heterogeneous micro-reduction is a correlation step, the aggregation step may be either trivial or non-trivial to allow us still to talk of emergence at the level of the whole. For even when the aggregation step is a trivial addition, the correlation step guarantees that 'the whole is more than the sum of its parts'. However, when the transformation step is an identification step, the aggregation step must be a non-trivial aggregation if we are to have emergence at the level of the whole. For again, a property cannot be called emergent if it is explainable in terms of a micro-theory in conjunction with trivial addition and identification, because then it is 'exactly equal to the sum of the properties of its parts' (such as in the case of the mass of a whole).

Thus we can define an emergent property as a property of a whole which is either (1) not explainable in terms of a micro-theory or (2) explainable in terms of a micro-theory in conjunction with (a) a non-trivial aggregation hypothesis and an identification hypothesis or (b) a correlation hypothesis (and either a trivial or a non-trivial aggregation hypothesis).

5.4.2 Reduction without levelling

As argued above, emergence may be seen as the opposite of ontological identity. In this sense the empirical thesis of emergentism may be seen, within the confines of epistemological verificationism (see 4.4), as an *ontological* thesis. It pertains to the things or substances we assume reality to be made up of, and to the properties or, if one wishes, the 'natures' we attribute to these things or substances. Reduction, on the other hand, is an epistemological issue. As argued extensively in the former chapters, reduction pertains to the logical relations between concepts, laws or theories. Thus, it is extremely important to realize that it is not things or properties that are being reduced, but either *concepts* of them or *statements* about them. Nagel (1982, pp. 364-5) also points out that reduction, as a thesis concerning logical relations between theories, should not be confused with the notion that properties are thereby being reduced. This notion is misleading, according to Nagel, because their is no way of knowing the properties or 'natures' of things without stating (postulating) them by some theory. "Accordingly, whether a given set of "properties" or "behavioral traits" of macroscopic objects can be explained by, or reduced to, the "properties" or "behavioral traits" of atoms and molecules is a function of whatever theory is adopted for specifying the "natures" of these elements" (Nagel 1982, p. 365).

I think that a great deal of the resistance amongst holists against reduction stems from the fact that they confuse the epistemological meaning of the term reduction with its everyday meaning: levelling, lessening, or diminishing (such as in sales reductions). The idea is then that in a scientific reduction not only concepts, laws or theories are being reduced, but also the ontologies to which they refer and that this involves, moreover, some sort of diminishment or even the elimination of these ontologies (a notion, by the way, to which many philosophers have contributed by talking about ontological reduction; see the former chapter). This is a serious misunderstanding. As argued in chapter 3 (section 3.4.2), in all types of reduction, excepting instrumentalistic reductions (where with the replacement of one theory by the other also the ontologies change), nothing changes at the level of the ontology of the reduced law or theory. The properties, things or phenomena to which a law or theory refers do not disappear, change or diminish in any way with the reduction of that law or theory. Reduction is a kind of explanation, not of explaining-away. On the contrary. As also argued in chapter 3, in all types of reduction, excepting perhaps approximative reductions, the reduced law or theory is actually being *consolidated* or even *reinforced* by the reducing theory, and this consolidation or reinforcement is transferred, so to speak, to its ontology. In the case of approximative reductions one could say, moreover, that a corrected version of the reduced law or theory is being consolidated.

Suppose that we would actually be capable of reducing the theory by which we specify what we actually mean by 'life' to, say, molecular genetics. Would we then stop living or live less of a life? Or suppose that we would be capable of reducing our 'theory of the mind' to, say, neurophysiology. Would we then stop having minds, have less mind or be less mind-ful? I dare not put my hand into the fire, that gases still have a temperature, even though this property has been theoretically reduced to the kinetic energy of molecules.

Thus, the reduction of laws or theories concerning higher levels of organization (wholes) to theories concerning lower levels (parts) does not mean that the higher levels themselves are thereby being reduced, or that they are being eliminated, diminished, lessened, or whatever. As stated by Bunge (1977, p. R79), "Reduction does not imply levelling: it relates levels instead of denying that they exist". "..reduction, to be legitimate, must account for emergence and not deny it. In particular, even if we succeed in explaining life in chemical terms, and thought in biological terms, we want to stay alive and think rather than die or be mindless. In short, we want *reduction without levelling*" (Bunge 1977, p. R81).

5.5 Methodological aspects of reduction

5.5.1 Analysis versus synthesis?

Acceptance of on the one hand the emergence thesis (as an empirical or ontological thesis) and on the other hand the fact that it does not contradict the reduction thesis, means that we can couple an ontological pluralism (the recognition of emergent entities and properties at higher levels of organization) to a moderate form of epistemological and methodological reductionism.

This strategy has been formulated by Bunge in terms of the following two methodological rules: "Rule 1. Start by studying every system on its own level. Once you have described it and found its patterns of behaviour, try to explain the latter in terms of the components of the system and the mutual actions among them. Rule 2. Look for relations among theories, and particularly for relations among theories concerning different levels. Never skip any levels. If reduction (full or partial [see below]) fails, give up at least pro tempore" (Bunge 1977, p. R80).

Radical reductionists accept the second part of the first rule but reject the first part and the second rule. Radical holists, at the other side, welcome the study of higher levels, but reject the element of reduction in both rules. As to the latter point, however, the question is whether we are not dealing with either one of the caricatures existing about holists (whether sketched by themselves or by others) or a confession of faith which has little or no meaning in actual research practice. Whatever scientific practice may be, it consists at least of attempts to understand and explain certain aspects of reality, which is usually preceded by description and classification. Thus, unless holists place themselves emphatically outside the context of science (which may apply to some New Age holists, but certainly not to biologists such as Mayr), they will generally join in such attempts. According to Nagel, in doing so they make use of the so-called analytic method, "the use of the so-called "abstractive method" - by concentrating on a limited set of properties things possess and ignoring (at least for a time) others, and by investigating the traits selected for study under controlled conditions. Organismic biologists [holists, RL] also proceed in this way, despite what they may say, for there is no effective alternative to it" (Nagel 1982, p. 445). This makes them in a certain respect, methodologically speaking, to moderate reductionists. This is confirmed by Popper who states that "The use of holistic experimental methods (such as cell transplantations in embryos), though inspired by holistic thought, may well be claimed to be methodologically reductionist" (Popper 1974b, p. 271).

Holists incidentally advocate a so-called 'synthetic' research method, but it is not clear what they mean by that. A synthesis is the putting together or assemblage of separate components into a certain whole. Apart from the fact that this is, at least according to holists themselves, impossible (for after all, the whole is more than the sum of its parts), one shall first have to make an analysis before he can come to a synthesis.

A stronger claim may be that in biology it is often easier, and more appropriate or useful, to explain the component parts, properties or behavioral traits of organisms in terms of (their function in) the whole than it is to explain the whole in terms of its parts. Such functional explanations are indeed very common and seem to be indispensable in biology. And because they do not appear in physics and chemistry, they make up an important argument in the holistic plea for biology’s autonomy (but see chapter 7).

5.5.2 Co-operating research programmes

All that has been said above does not at all imply that reductionism is salvational. On the contrary. To put is bluntly, philosophically or methodologically speaking, reductionism is a failure, at least in its radical form. There are four more or less coherent reasons for this claim.

Firstly, radical reductionism is characterized by either the denial of the existence of emergent entities, properties and phenomena at higher levels of organization or the denial of the importance of studying them. One can easily imagine the annoyance of holists in this respect: "When a well-known Nobel laureate in biochemistry said, "There is only one biology, and it is molecular biology," he simply revealed his ignorance and lack of understanding of biology" (Mayr 1982, p. 65).

Secondly, before we can even think of a reduction, there must first be something to be reduced! Before we can even think of micro-reductions, we will first have to have macro-laws and -theories that call for such reductions. And of course these macro-laws and theories must first be discovered or developed. In other words, "Before we can even attempt a reduction, we need as great and detailed a knowledge as possible of whatever it may be that we are trying to reduce. Thus before we can attempt a reduction, we need to work on the level of the thing to be reduced (that is, the level of "wholes")" (Popper 1974b, p. 283; compare also rule 1 of Bunge above).

That is to say, we must first have ’holistic’ research at the level of the whole before we can even think of attempts at reduction. This point may seem as trivial as the emergence thesis, but it is so neither. It means that holism and reductionism, when characterized in terms of *research programmes* which are directed at, respectively, the whole and its component parts, do not so much exclude as complement each other. Even stronger, they are *mutually dependent*. Reductionistic research programmes depend on holistic programmes for providing macro-laws or -theories to be reduced, and holistic research programmes depend on reductionistic programmes for carrying out these reductions (that is, for providing deeper explanations of these laws or theories).

The model with which this mutual dependency can be described is Zandvoort’s (1986a) model of *co-operating research programmes*. This model applies to research programmes which are directed at different domains or at different levels of organization, contrary to programmes which are directed at the same domain, which are often competing programmes. The terminology to characterize co-operating research programmes and their mutual relations is that of *guide programmes* and *supply programmes*. A guide programme is a programme that points the way to some problem which it cannot resolve itself, for example, the description of certain phenomena which it has discovered but cannot explain. Such a programme is called a guide programme, because it acts as a guide, so to speak, for one or more other programmes which may attempt to solve the problem. A supply programme is a programme that succeeds in solving a problem that was raised at the level of a guide programme, for example, by providing an explanation of the phenomena discovered by the guide programme. Such a programme is called a supply programme because it supplies the guide programme with a solution to its problem.

There is a mutual dependence between guide and supply programmes in the sense that the former need the latter for solutions to their problems, while the latter need the former for generating these problems. Naturally, this is not to say that both types of programmes cannot also operate independently of one another, at their own respective levels, but when it comes to relations between levels, they are mutually dependent.

When we apply this model to reduction problems, we can say that holistic research programmes will generally act as guide programmes for reductionistic supply programmes by discovering or developing macro-laws or -theories at the level of some whole which they cannot, however, for lack of the appropriate means, explain themselves. In such cases, reductionistic programmes will act as supply programmes for these holistic guide programmes if and in so far as they succeed in developing adequate micro-theories and suitable bridge principles with which these macro-laws or -theories can be explained. In the next chapter I will discuss an example of heterogeneous micro-reduction in biology which nicely illustrates this co-operation and mutual dependence of holistic and reductionistic research programmes.

5.5.3 Partial reduction

Thirdly, radical reductionism is a failure because successful reductions, especially heterogeneous micro-reductions, are extremely rare, even within and among physics and chemistry (Popper 1974b; Bunge 1977, 1982), not to mention biology, therefore. The reason for this is that, apart from the fact that the discovery or development of macro-laws and -theories in biology appears to be no easy matter, not only developing appropriate micro-theories proves to be extremely difficult, but also finding the right bridge principles in the form of aggregation and transformation hypotheses. It will be clear that this problem increases with the increasing complexity of higher levels. I will illustrate this point further in the next chapter.

Fourthly, and finally, successful reductions (of theories) are not only rare but also almost always incomplete or partial, even in physics (Popper 1974b; Bunge 1977; Zandvoort 1986b). As Popper (1974b, p. 260) puts it, "hardly any major reduction in science has ever been completely successful: there is almost always an unresolved residue left in even the most successful attempts at reduction". This means that only part of a theory to be reduced, only some of its statements, follow logically from the reducing theory (and auxiliary hypotheses), but others don’t.

What applies to physics applies *a fortiori* to higher level sciences such as biology. Though today many biological phenomena can be explained partially in physico-chemical terms, successes which are reflected in the afore-mentioned growth of biochemistry, molecular biology and molecular genetics, even the reduction of Mendelian genetics to molecular genetics is still extremely problematic and incomplete. If even such ’small step’ reductions are so problematic, then it is of little or no use racking one’s brain about ’large step’ reductions[38], such as advocated by some radical reductionists: the complete reduction of psychology and sociology to biology, of biology to chemistry, and of chemistry to physics. Radical reductionism is characterized in this respect by extremely unrealistic research programmes, such as the full reduction of all other sciences to physics as proposed by members of the Vienna Circle or, conversely, the full reduction of all other sciences to psychology as proposed by Ernst Mach (see Bunge 1977, p. R80).

There is another sense in which many reductions are partial, which is that they concern only a part of the domain of the theory to be reduced while other parts have yet to be reduced. Of course, this is no argument against reduction in itself, but it does mean that for concrete insights in the domain of some macro-theory that has not (yet) been reduced, one can turn only to this macro-theory itself, or to the 'holistic' research programme that has this theory as its hard core. And this in turn means that as long as a macro-theory has not been completely reduced, that is, as long as its 'in principle reducible' domain is larger than its reduced domain, the relevant holistic programme will always have a lead on reductionistic programmes (Zandvoort 1986b). This point, too, will be illustrated in the next chapter.

5.6 Summary and conclusion

One of the chief contradistinctions between holism and reductionism in biology is the one between the emergence thesis and the reduction thesis. Holists embrace the emergence thesis but reject the reduction thesis. Reductionists embrace the reduction thesis but reject the emergence thesis. I have argued, contra reductionists, that the emergence thesis is a valid and universal ontological (empirical) thesis, which is, however, contra holists, not contradictory to the reduction thesis. I have even argued that emergence may actually be seen as the opposite of ontological identity and that, therefore, we couldn't even conceive of micro-reductions if there were no emergence. Finally, I have argued that holism and reductionism, when characterized in terms of research programmes which are directed at, respectively, the whole and its constituent parts, are mutually dependent and, therefore, should co-operate. Reductionistic programmes depend on holistic guide programmes for providing macro-laws and theories that call for deeper explanations (reductions), and holistic programmes depend on reductionistic supply programmes for providing these deeper explanations. In part 2 of this book I will apply this thesis to holistic and reductionistic research programmes in ecology. In the next chapter I will apply it to relations between programmes in animal physiology, molecular biology and physical chemistry.

[38]The terms 'small step' and 'large step' reductions were suggested to me a long time ago by Theo Kuipers.