

Conservative reduction of biology

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(Final version)

Abstract*

The paper argues in favour of a reductionist strategy in the philosophy of biology in order to maintain the unity of science. After considering the problems in the current state of the philosophy of science that beset both the anti-reductionist and reductionist camps, I design a conservative, non-eliminativist, alternative reductionist strategy based on the theoretical possibility of constructing functionally defined sub-concepts in biology that are nomologically coextensive with physical descriptions. This *theoretical* link between biology and physics makes it possible to understand the original and operational biological concepts as abstractions from these biological sub-concepts. Thus, in a sense, we can ‘serve two masters’, preserving the fundamental role of physics while allowing biology its proper sphere of explanatory autonomy, and thus its scientific character. Since this abstraction step is an intra-theoretic one, the scientific quality of the original biological concepts can be vindicated because both epiphenomenalism and eliminativism are avoided, a result that is not available in standard reductionist or anti-reductionist approaches. Against this background, we can argue furthermore that biological kinds are natural ones and that biology adumbrates laws and explanations of different degrees of abstraction.

1. *Introduction and the dilemmas for the scientific quality of biology*

It is generally taken for granted that biology provides functional explanations. These are specific causal explanations often couched in terms of selected effects or given contributions to certain capacities or fitness functions of biological systems (the locus classicus is Wright 1973, and Cummins 1975). We shall say more about biological functions in section 5. Here, let us simply take for granted that functional explanations are somehow about causally efficacious properties. This is sufficient to ground the claim that each functional property token is identical with something physical (see among others Kim 2005 ch. 2, Kitcher 1984, and Rosenberg & Kaplan 2005). Otherwise there would be serious problems with at least one of the following widely accepted working hypotheses: 1) biological properties supervene on complex configurations of physical properties (see among others Rosenberg 1978, Weber 1996); and 2) physics is causally, nomologically and explanatorily complete with respect to biology (see among others Papineau 2002, appendix).

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Biology, for instance, seeks to explain causal relations between given genotypes, phenotypes and the environment or evolutionary changes of the genotype frequencies due to different selective forces in changing environments. Both such local causal relations and more extensive evolutionary processes, however, supervene on complex configurations of physical properties and their changes. These, in turn are *in theory* completely explicable in terms of physics. More precisely, under the condition that biological properties have functional effects, the production of these effects supervenes on a corresponding causal interaction among physical properties, where no non-physical forces are involved. This fact suggests that any functional property token is identical with something physical (see especially Kim 2005, ch. 2 for the general argument in detail). Biological property tokens therefore are not epiphenomena, but causally efficacious entities, and biological functional explanations can be understood as causal ones that focus on specific causal effects of these entities (according to the very notion of a biological function).

Against the background of this general framework, we come to the conclusion that biology refers in different terms to property tokens to which physics also refers. One may then ask how biological concepts, laws and explanations are related to the corresponding physical descriptions (that are composed concepts), laws and explanations. Of course, the answer depends on what we mean by 'laws' and there is an ongoing debate about whether there are any laws in biology and whether biological explanations presuppose underlying laws (see Rosenberg 2001). The reductionist approach I propose constitutes an argument that biology does contain laws, and that biological explanations thus have a nomological underpinning (see also Sober 2000, ch. 1.4). It furthermore enables us to take biological kinds as genuine natural ones. However, these issues presuppose at first a more detailed consideration of biological concepts and their relation to physics.

To launch this discussion, let's start with the main shortcoming of the anti-reductionist position (I'm thinking here of arguments going back to Fodor 1974, and Putnam 1967 / 1975, like for instance in Kitcher 1984). According to these arguments, biological concepts may and are often not bi-conditionally related to physical descriptions. Functional explanations that are couched in such terms may then constitute some kind of autonomous and unifying explanatory level. For instance, *one* genetic description and explanation may refer to entities that come in fact under *different* physical descriptions and explanations. Pace multiple realization, this fact should rather constitute an *anti-eliminativist* than an *anti-reductionist* argument, and a central focus of the paper is to spell this claim out. Why? Actually, in any case where a biological concept cannot be bi-conditionally related to a physical description, more precisely, if no nomological coextension between both descriptions can be established, then no *anti-reductionist* position has an argument to take these biological concepts as being about the same property tokens as physics is. Within an anti-reductionist framework, it is moreover suggested that the biological concepts are actually not about the *same* entities in the fine-grained sense, but are instead about *different* properties (see Michael Esfeld's contribution to this volume; see also Esfeld & Sachse 2010, ch. 5, and Sachse 2007, ch. 3).

This consequence has direct relevance to the usual pattern of argument by which anti-reductionism maintains the autonomy and scientific quality of biology. If one sticks to the mentioned multiple realization as an anti-reductionist argument, claiming that bi-conditional relations cannot be sufficiently established to enable the theoretical reduction of biology, this then leads to property dualism, with the further implication that the biological properties are

epiphenomenal. If we go to the logical end of the anti-reductionist argument, we encounter the paradox that anti-reductionism makes rather eliminativism plausible than the claimed autonomy of biology. In order to avoid epiphenomenalism, it thus *has to be theoretically possible* to construct biological concepts that are bi-conditionally related to physical descriptions, which then means to consider the relation between biology and physics from a reductionist perspective.

However, the fact that anti-reductionism suggests epiphenomenalism and therefore also eliminativism does not imply that *non-eliminativist* (conservative) reduction is a trivial task. Rather, reductionism faces two dilemmas. The first dilemma derives from the fact that a reductionist approach, which is classically based on bi-conditional relations between biological concepts and physical descriptions (like Nagel 1961), seems to lead to another kind of eliminativism. To understand how this consequence comes about, just imagine for one moment that there were no multiple realization such that one could establish Nagelian bridge-laws in a bi-conditional manner, or, if you prefer, in terms of Kim style functional reduction (Kim 1998, ch. 4 and 2005, ch. 4). Thus, any biological concept *B* would be nomologically coextensive with a physical description *P*. But even though we may then vindicate the claim that biological concepts are about causally efficacious properties (more on that in section 2), the causal, nomological and explanatory completeness of physics is such that ultimately, we can in principle eliminate biology in favour of physics, even though not in practice. In other words, if nomological coextension can be established between *all* biological concepts and physical descriptions, physics would theoretically replace biology.

The second dilemma can be spelled out as follows: by using the multiple realization thesis to refute classical reductionism (more on that in section 3), it is nonetheless possible to develop another kind of reductionism that also ends up implying eliminativism. It turns out that it is theoretically possible to construct physical theories in such a way that they model in a more or less isomorphic way the complete set of biological theories (see Bickle 1998). This possibility arises in the following stages: a) due to token-identity and the completeness of physics, one may theoretically construct physical theories that model any causal relation considered by biological theories, even though such a modelling may not constitute bi-conditional relations because of multiple realization; b) due to their integration into physics, the constructed physical theories are the preferred ones, leaving no logical space for any *sui generis* biological theories (that seem to be disqualified anyway so far). This eliminativist result does not change if the reductionist approach is some kind of combination of the classical or functional model of reduction and “new wave reductionism”, or if the “new wave” collapses into the classical model (see Endicott 1998 for that collapse). To sum up, it seems that both the anti-reductionist and the reductionist approaches look somehow alike by suggesting the theoretical replacement of biology by physics or constructed physical theories.

De facto, one may currently not replace biology for simple instrumental reasons and also estimate that there is little likelihood to do so one day. However, instrumental reasons become stronger if one can argue how exactly biology can be *about causally efficacious property tokens* (I shall refer to this point by “*Cau*” in what follows) and at the same time show why its functional explanations are *theoretically not replaceable* by physical ones (I shall refer to this point by “*¬Rep*” in what follows). My discussion, then, follows the argument that can be made to conjoin “*Cau*” and “*¬Rep*”. I shall come back to instrumental reasons at a later stage. At this point, to recap, it is obvious that “*Cau*” and “*¬Rep*” are two sides of the same coin

called multiple realization in the mainstream approaches. We have shown that the antireductionist approaches cannot establish “*Cau*” and therefore hardly “ $\neg Rep$ ”. If there were no multiple realization and nomological coextension thus could be established between all biological concepts and physical descriptions, then classical and functional models of reductionism may vindicate “*Cau*” but not “ $\neg Rep$ ”. If there is multiple realization, then new wave reductionism enters the scene, however, without justifying the conjunction of “*Cau*” and “ $\neg Rep$ ” either.

The following section considers the possibility to establish nomological coextension in the framework of functional reduction under the condition that there is no multiple realization. In this context, it is possible to vindicate “*Cau*” for biological concepts. In section 3, I show how to establish nomological coextension starting with multiple realization. By means of a causal argument, I will establish nomological coextension between so-called functional sub-concepts and physical descriptions. The end result is once again the vindication of “*Cau*”, here for the constructed sub-concepts. Section 4 will then focus on the relationship between these sub-concepts and the original (multiply realized) biological concepts. The aim of this section is to show how the original biological concepts may inherit “*Cau*” from their sub-concepts even though being non-replaceable by physics (“ $\neg Rep$ ”) due to multiple realization. The last section will then apply these considerations to several other debates in the philosophy of biology – among others the notion of biological function, laws in biology and biological natural kinds.

2. *Functional reduction without multiple realization*

The structure of this section is threefold. First of all, I need to represent biology for the previously raised issues and aims of the paper. This will be done by some comments on biological functions and explanations. This, second, enables us to apply the model of functional reduction and reductive explanation, which in turn, third, shows how one can vindicate that biology is about causally efficacious property tokens (“*Cau*”) if there is no multiple realization.

By no means, a single paper may represent the entire domain of biological inquiry. However, for a consideration of reductionism, the following two issues may sufficiently represent biology: 1) any biological concept can be functionally defined in order to provide special kinds of causal explanations. Thereby, biological concepts are about functions being defined in the context of evolutionary biology since, as Dobzhansky put it, “nothing in biology makes sense except in the light of evolution” (Dobzhansky 1973). While the so-called etiological approach refers to the evolutionary *past* in order to determine what biological functions are, other approaches determine biological functions in terms of causal dispositions to contribute to the system’s capacities or fitness under the *given* environmental conditions (see Wright 1973, and Cummins 1975; see among others also Bigelow & Pargetter 1987, Millikan 1989, Neander 1991, Griffiths 1993, Kitcher 1993, Mitchell 1993, Godfrey-Smith 1993 and 1994, Amundson & Lauder 1994, Manning 1997, Schwartz 1999, Wouters 2003, Arp 2007, and Mossio et al. 2009). Here, nothing hangs on a particular concept of biological functions. However, section 3 will be an implicit critique of the etiological approach, and

section 4 constitutes in turn an implicit strategy to spell out its compatibility with the causal-dispositional approach (that will be made more explicit in section 5).

2) Any functionally defined concept of biology refers to something physical (token-identity). Within biology, any entity is most completely described and explained in terms of molecular biology. This point pays heed to another all encompassing paradigm of biology – the molecular approach to any biological property is a mechanistic one (cf. Machamer, Darden and Craver 2000). Once again, nothing special hangs on a particular interpretation of this paradigm or research strategy since both reductionists and anti-reductionists accept some pre-eminent importance of molecular biology. This paper shall only focus on how to establish a reductionist link between biology and physics. Since the arguments are constructed on a high level of abstraction, one may easily apply them to the debate about whether or not particular branches of biology are reducible to molecular biology as well.

Against this background, we now consider how to justify “*Cau*” – that biology is about causally efficacious property tokens. As explained in the introduction, one has to relate the physical and biological concepts, laws and explanations in a bi-conditional manner. Otherwise, we could not say that biological concepts, laws and explanations are about the *same* entities as physics instead of being about *different* ones, and keeping the completeness of the physical world in mind, *epiphenomenal* ones. If there is no multiple realization, nomological coextension between physical and biological concepts, laws and explanations can be established by the model of functional reduction. To see this, let us follow, with a few tweaks, the central steps of the functional reduction model that reconsiders previous issues in a more precise way (Kim 1998, ch. 4, and 2005, ch. 4):

1. We functionally define any concept *B* of biology. Independently of the very notion of biological functions at this point, the general argument for this approach can be spelled out as follows: if biological concepts are not functionally formulated in causal terms, then no causal explanation could be based on them. Depending on the very notion of biological functions, the functional formulation spells out what the characteristic causes and effects are. In this sense, the difference between physical and biological definitions of biological properties is not only of terminological nature, but there is a difference in what is understood as characteristic. Keeping in mind the evolutionary context, the difference between the biological and physical ways to describe and explain biological properties becomes evident: the biological definition relates causes and effects in the most general way to the framework of natural selection, which is what endows it with *functionality*. These functional definitions are more abstract than those of physics, where the focus is on *any* causal power the property exhibits.

2. We look for the physical base, often called physical realization, of biological functions. For a lot of biological property tokens, their exact physical structure is of course an open empirical question. But this empirical fact concerning current research does not alter the metaphysical issue. Since we take ontological reductionism for granted, there is no question *whether* biological property tokens are identical with *something* physical. Additionally, the reductionist debate is not primarily concerned with instrumental applicability and thus does not imply any normative component like claiming that reduction *should be* effected in biological research projects. Reduction is not a pragmatic matter, but is instead generally concerned with creating a coherent and unified system of scientific theories and possible levels of explanations. Furthermore, in this paper, I shall argue in section 4 that there are good

scientific reasons for retaining a biological vernacular in order to argue against its theoretical replacement by physics (“ $\neg Rep$ ”).

3. Given the first two steps, it is then in theory possible to explain reductively, which means in terms of physics, how biological property tokens are caused and cause the effects that characterize their functioning (see for the general idea of reductive explanations Chalmers 1996, pp. 42-51). The main characteristic of any kind of *reductive* explanation is its relative nature – to explain something (e.g. biological) in different and more detailed (e.g. physical) terms. As taken for granted in step 1, biology provides functional explanations. Since any of these causal explanations refers to something physical (step 2) and physics is causally, nomologically and explanatorily more complete than biology, physics can provide more detailed causal explanations of the biological causal relations (that are outlined in any functionally defined concept *B* and an according biological functional explanation). These reductive explanations are commonly seen as mechanistic explanations (see also Craver 2001 and 2006). One may note that in fact such reductive mechanistic explanations in terms of physics are quite common in biology and, similarly, molecular biology may provide on its own reductive (mechanistic) explanations as concerns the properties and causal relations considered by any other biological branch. Let me shortly illustrate these three steps by means of some biological examples.

Step 1: *Escherichia coli*, a bacterium that is often used in genetic research, contains genes or regions in the genome that are responsible for its cell-wall biosynthesis. To simplify, let us focus on genes that code for membrane proteins. Since the synthesis of these proteins are required for the growth of the cell before cell division, it is accordingly possible to functionally define the genetic bases: the rate of protein synthesis means a contribution to the possible growth rate, which can be, under optimal growth conditions, equated with fitness (see also Waters 1994 and 2007 for the discussion of the gene concept).

Step 2: Researchers have mapped the physical structure of the genetic base being responsible for the cell wall. For instance, they have sequenced the *mrdA* (Murein cluster d) that plays a crucial role for the cell-wall biosynthesis. This means in the ideal case that one has identified the physical structure that, given certain physical conditions in the cells, will bring about the expression of the proteins (or other effects) from the genes or genetic regions in question. To sum up and simplify the issue, the DNA sequences within the *E. coli* genome are physically identified as the coding sequence for these specific proteins, with these specific functions, produced under normal physical conditions in the cell.

Step 3: The description of any such gene and the explanation of the production of its characteristic effects may theoretically use only physical concepts. Because of the completeness of physics, it may employ only concepts of physics, explaining in a mechanistic manner the causal relation from the gene to its phenotypic effect. Simplified, it is a physical mechanistic explanation of how DNA sequences are transcribed into mRNA, which then is translated into chains of amino acids that, in turn, are folded into proteins that are incorporated in the cell wall, bringing finally about the phenotypical effects that define the gene in question.

Under our hypothesis that excludes multiple realization, these steps of the functional reduction model show how each biological description and explanation of a property can in principle be nomologically correlated with a corresponding physical description and explanation. To put it differently, if the biological concepts are functionally (and thus

causally) defined, then the biological and the corresponding physical descriptions are nomologically coextensive because: a) our assumption that there is no multiple realization; b) ontological reductionism; and c) the completeness of physics. Once the nomological coextension between biological concepts and physical descriptions is established, it is possible to deduce biological explanations and laws from physics. There thus remains no threat of epiphenomenalism for biological properties (“*Cau*” is justified). Both biology and physics are, then, about the same properties even though they refer to these properties in different terms. In this way, the biological approach has a higher degree of abstraction since it does not spell out in detail the way in which the characteristic effects of genes are produced.

To sum up, if there is no multiple realization, functional reduction and reductive explanations establish an argument for the scientific quality of biological concepts, laws and explanations *in the sense that* they are about certain specific causal powers and causal relations (“*Cau*”). However, keep in mind that an eliminativist approach to biology can still be based on the preference of the physical reductive explanations because of their completeness. “*¬Rep*” of the biological explanations is not yet justified.

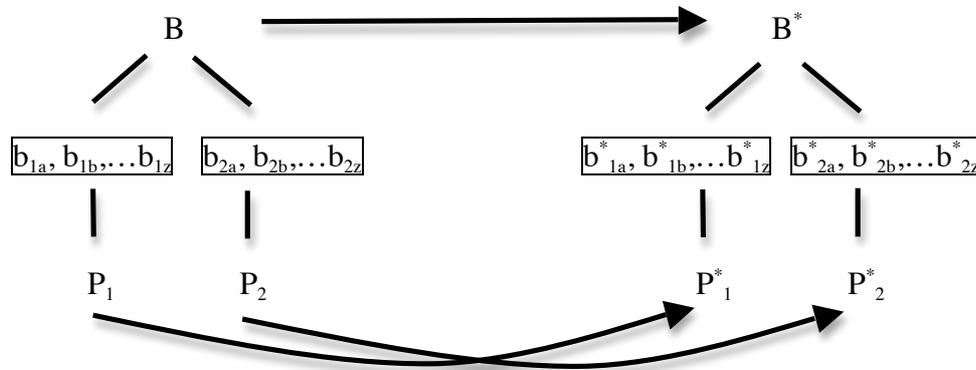
3. *The challenge of multiple realization*

The aim of this section is twofold. First of all, I shall make the representation of biology more realistic by incorporating the fact that its properties are often multiply realized or at least multiply realizable. To put it differently, biological concepts often refer or may refer to property tokens in a homogeneous manner that are heterogeneously described in terms of physics. The question then is how to justify “*Cau*” for the functional similarities that are brought out by biological concepts – that they are about causally efficacious property tokens even though no correspondingly homogenous physical description exists. As we pointed out above, “*Cau*” depends on the theoretical possibility of establishing nomological coextension between biological concepts and physical descriptions. Since it follows from the definition of multiple realization that the original biological concepts cannot figure in such bi-conditional correlations, the second aim of this section is thus to outline an argument to theoretically construct so-called functionally defined biological sub-concepts that are no longer multiple realizable. On this basis, “*Cau*” can be justified as concerns these sub-concepts.

Taking ontological reductionism and the completeness of physics for granted, physics can account for any property token that biology describes and explains. Hence, there are biological property tokens that are described and explained in physical terms and in terms of biology. The characteristic difference between these two kinds of descriptions (and thus explanations) lies in the referring to the very same properties by allowing for the fact that biology focuses on the causal dispositions of the very properties that are or may become salient for selection. Consequently, the biological approach is an abstract one as compared to the physical approach that is more detailed and relatively complete. There thus is an asymmetry between the more abstract biological homogeneous descriptions and explanations and the more detailed heterogeneous physical descriptions and explanations. This fact is brought out by the argument of multiple realization that constitutes, because of this inherent asymmetry, an argument against the nomological coextension of physical and biological

concepts, laws and explanations. As concerns biological properties in general, the central point of multiple realization can be illustrated as follows:

Biological concepts that constitute functional explanations refer, because of functional similarities, in a homogenous way to biological property tokens in the world.



Physical concepts that constitute causal reductive explanations refer, because of physical differences, in a heterogeneous way to biological property tokens.

Since the matter is quite crucial for what follows, let me be more precise on multiple realization and the interpretation of it. In order to avoid letting biological properties slide into epiphenomena, biological property types are taken to be biological concepts (see Esfeld's contribution to this volume, Esfeld & Sachse 2007 and Sachse 2007, ch. 2). The functionally defined concepts of biology then may refer *multiply* in the following sense: they refer *homogeneously* to biological property tokens that are identical with physical configurations, while the latter come under *different* physical descriptions due to their varying composition. Multiple realization is, so understood, an empirical fact; for our purposes, there is nothing astonishing about it, since the approach of biology is more abstract than the physical one. Thereby, the focus on natural selection constitutes the argument for multiple realization (see Papineau 1993, p. 47, and also Rosenberg 2001): depending on the given environmental conditions, only some of the causal powers of a given physical configuration are pertinent for selection. Here, if you like, one may take the abstractions from physical details that do not change the biological function as motivated by more than instrumental simplifications of complex physical structures and changes. The epistemological focus in biology, then, is on what matters in the context of evolution, and this constitutes the ground for any further biological simplification for instrumental reasons.

The question then is how this well-established fact of multiple realization fits with the token identity claim and the completeness of physics so that we will be able to vindicate "*Cau*". According to the scheme of multiple realization, not everything that comes under B also comes under a single physical description P_1 . Here, P_1 is a placeholder for a detailed homogeneous physical description that, because of multiple realization, only applies to a subset of entities that come under B . Therefore, functional reduction as it stands (section 2) does not provide for a nomological coextension between the descriptions of biology and physics. It shows a way from physical to functional concepts of biology but not the other way round.

The question is whether the so-called local or species-specific reduction of Lewis and Kim may be used to construct biological concepts that are nomologically coextensive with the corresponding physical description. To discuss this strategy, let us refer to the common example in the philosophy of mind that goes as follows: the concept of pain reduces in one species, say humans, to one physical concept – e.g. “firing of C-fibres” (P_1) –, it reduces in another species, say octopuses, to another physical concept (P_2), etc. (see Lewis 1980 and Kim 1998, 93-95; 2005, pp. 24-26). On that basis, one has so-called species-specific concepts such as “pain-in-humans” ($B-P_\Omega$) and “pain-in-octopuses” ($B-P_\Delta$). These concepts are not purely functional concepts of the special sciences but something like semi-functional-semi-physical concepts with P_Ω and P_Δ as their physical parts. The functional concept B (e.g. “pain”) is in this way relativized to particular species (or even has to be relativized to local physical structures if there are physical differences within the species) such that no common property specification of the function B remains (see Kim 1999, pp. 17-18).

To probe the meaning of this loosening of the functional from the physical concept, one only has to focus on the problem how to argue that species-specific concepts like “pain-in-humans” ($B-P_\Omega$) do not refer to *different* physical structures. To put it differently, is it possible to use *physical* criteria at the biological level in order to establish nomological coextension with physical descriptions? There are three possible relations between the semi-functional-semi-physical concepts $B-P_\Omega$ ($B-P_\Delta$) and the physical description P_1 (P_2):

1) If the physical part in the semi-functional-semi-physical concept $B-P_\Omega$ has *nothing* to do with the physical concept P_1 , there is obviously no argument for nomological coextension. Pain in humans is still multiply realizable. This can easily be seen in the context of the functional model of reduction (section 2): the reductive explanations that are based on P_1 are not linked to P_Ω but only to B , to which the physical concept P_1 is *de facto* not nomologically coextensive; in other words, since there is no link between P_1 and the added physical criterion (P_Ω) in $B-P_\Omega$, that physical criterion cannot establish a nomological coextension between $B-P_\Omega$ and P_1 .

2) If the physical element in the semi-functional-semi-physical concept $B-P_\Omega$ *contains parts* of the physical concept P_1 ($P_1 =$ conjunction of P_{1*} and P_Ω), then the link between both concepts is still too weak to constitute nomological coextension. The physical criterion P_Ω is of course nomologically coextensive with the corresponding part (P_Ω) of P_1 , but it is not nomologically coextensive with P_1 since there can be configurations in the world that are described only by P_Ω but not by P_1 . If there is any possibility that the *conjunction* of B and P_Ω would be nomologically coextensive with P_1 , then B has to be about something that is included in P_1 but not in P_Ω . Similarly, in the conjunction of B and P_Δ , B has to be about something that is included in P_2 but not in P_Δ . What is that something the B expresses that is physically different in both cases? If B is not about something physically different, then there would be no multiple realization to begin with. So, B has to be about something physically different, say about P_{1*} in the first and about P_{2*} in the other case. Then $B-P_\Omega$ cannot be nomologically coextensive with P_1 since $B-P_\Omega$ may refer both to the conjunction of P_Ω and P_{1*} ($= P_1$) and other possible conjunctions like that of P_Ω and P_{2*} .

3) It thus seems that unless the semi-functional-semi-physical concept $B-P_\Omega$ contains entirely the respective physical concept P_1 , any coextension between the $B-P_\Omega$ and the physical concept P_1 is a mere *contingent* fact. If, however, $P_\Omega = P_1$, then we get $B-P_1$ and thus we are back to the starting point where the link between B and P_1 (B and P_2) is unclear.

Since this problem appears in any application of the species-specific or structure-specific model in biology, it is clear why this approach cannot make “*Cau*” intelligible: unless a given semi-biological-semi-physical concept does not contain the respective physical concept (like P_1 or P_2), no nomological coextension with physical concepts can be established. If there is no such nomological coextension, it remains unclear what the biological part B in the semi-biological-semi-physical concept is about – what the common specification of B is. Somehow worse, if the semi-biological-semi-physical concept in fact contains the physical concept P_1 , then there is no link at all between B and physics. To sum up the essential point, adding *physical* criteria to biological concepts does not help to make intelligible how “*Cau*” can be justified for any biological concept B (and thus of biology in general).

Against this failure, one has to look for another theoretical strategy to establish nomological coextension between the descriptions of biology and physics. To do so, let me reconsider multiple realization once again in terms of the causal-functional theory of properties (see Michael Esfeld’s contribution to this volume). If local physical structures coming under one concept B are described in terms of different physical concepts (like P_1 and P_2 in our schema), then there is a difference in composition among these structures. Each of these physical concepts picks out a minimal sufficient condition to bring about the effects that define B , given certain normal background conditions. In order to get from structures coming under P_1 to structures coming under P_2 , one has to substitute at least one of the parts that are *necessary* to bring about the effects in question with a part of another type. If – and only if – one takes the causal-functional theory of properties for granted, any such replacement implies a systematic difference in the way in which these structures cause the effects that define B . It is then excluded that one can replace a local physical structure of type P_1 by a local physical structure of type P_2 , thus obtaining a different physical realizer of B *without* making a causal difference (see also Kim 1999 and 2005, p. 26).

If the effects that define B can be brought about by two or more different physical properties, we will find a difference in the production of side effects that are systematically linked with the main effects in question. Think of different causal interactions with the physical environment within the cell when a gene is transcribed and proteins are synthesized that make up its characteristic phenotypic effects. For any such difference in the causal sequence from the DNA transcription to the protein synthesis, there exists the possibility that the difference may become pertinent to the shift of selection pressures within the target environment (see Rosenberg 1994, p. 32). Consequently, that difference can *in principle* also be considered in terms of the concepts that are proper to biology to which B belongs. Here, more precise functional definitions will help us to account for different reaction norms, and thus, physical differences. A reaction norm can be described by a mathematical function over the different probabilities of fitness contributions in different environments. Against this background, for the concept B (that is multiply realized by P_1 and P_2), it is possible to conceive two functional sub-concepts B_1 and B_2 taking different reaction norms into account (see also Bechtel & Mundale 1999 with regard to the more fine-grained functional concepts of the special sciences).

It follows from the outlined argument that the sub-concepts are thus no longer multiply *realizable* since *any* physical difference that is constitutive for multiple realization (that is a different way to bring about the effects that define B) leads to specific functional differences – that is, to a unique reaction norm. The functionally defined sub-concepts thus correspond by

definition to one single type of physical configuration that brings about the effects that define B in one particular way. Having the sub-concepts so defined, they are thus nomologically coextensive with the physical concepts P_1 and P_2 .

For instance, let us consider a gene of *E. coli* that has effects that are pertinent for its fitness and that is accordingly functionally defined in terms of biology. Think of our cell-wall biosynthesis example. The gene tokens coming under B are defined by their characteristic expression of membrane proteins that are crucial for the cell growth of the bacterium before cell division, etc. Independently of our chosen level of genetic simplification, the gene tokens coming under B are identical with certain physical configurations (DNA sequences) that are described differently in terms of physics (by P_1 and P_2) since there are differences in the physical composition of the DNA sequences in question. Nonetheless, because of the redundancy of the genetic code, all these physically different DNA sequences code for proteins of the same type (or any other effect that is considered in the functional definition B). The crucial point here is that according to the physical differences between P_1 and P_2 , there are different physical paths to bring about the effect in B . These different ways to produce the effects (the proteins for instance) are, as current research confirms more and more, systematically linked with possible side effects or reaction norms (see below). Differences in side effects have an effect on the overall evolutionary trajectory, as for instance in that they express functional differences that lead to different selection pressures, such that so-called codon-bias. Codon-bias is a statistical skewing towards a specific DNA sequence (thus specific physical configurations of genes). This arises because the physical differences of the DNA sequences have been and continue to be pertinent to natural selection *under certain environmental conditions*.

To have a better idea of such functionalizable side effects or reaction norms, think of differences in the speed or the accuracy of the protein production, of which we have quite illustrative and well-confirmed examples (see among many others Bulmer 1991, Hartl et al. 1994, and Gerland & Hwa 2009 for such functional side effects in certain genes of *E. coli*, see Mukhopadhyay et al. 2008 for functional side effects in plants, see Kimchi-Sarfaty et al. 2007, Yang & Nielsen 2008, and Moses & Durbin 2009 for functional side effects in certain genes of mammals, see Sotzlfus 2006, and dos Reis & Wernisch 2009 for general and comparative considerations). To sum up, depending on the environmental conditions, certain DNA sequences are more optimal than others (and thus not selectively neutral) and this can be taken into account in more precise functional definitions.

The issue is of course more complicated than it is sketched out here. One may thus object that the codon-bias that results out of the given selection pressure depends on many other factors than only on a faster production of proteins. Of course it does. The selection pressure (and thus the codon-bias) depends for instance on the selective importance of the produced proteins. If the protein is not that important for the organism, the selection pressure and thus the codon-bias for a particular DNA sequence is accordingly low. However, selection pressure depends on the adaptive landscape. Shifts in environmental conditions can activate hitherto latent selection pressures. At this point it becomes clear to what extent the sub-concepts (that take into account that very issue) are *theoretical* constructions. Let me note here that this quick example from the empirical data serves mainly to show at what point the construction of functionally defined sub-concepts may represent the successes and lacuna of current genetic research as it searches for functional differences that correspond to physical

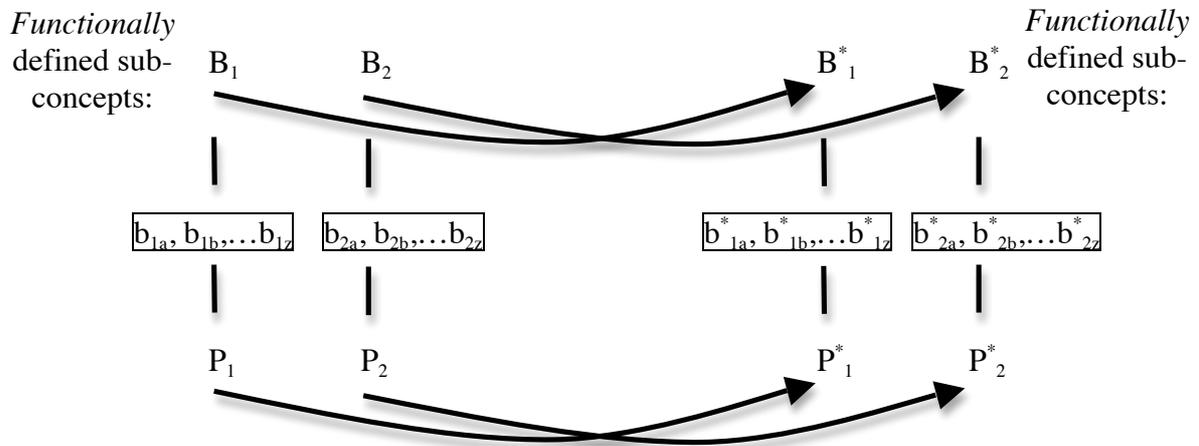
differences. This fact therefore suggests that biology has in principle the means to consider the reaction norms of P_1 and P_2 and to construct functionally defined sub-concepts. To put it differently, under certain environmental conditions, it seems *necessary* to take into account functional differences that result from even minor physical differences in order to coherently explain evolutionary pathways.

Another crucial issue is linked to mutations and the frequencies of their appearance. One may object that mutation frequencies (and thus appearances of physical differences) are sometimes so high that in fact no selection pressure occurs in favour of or against specific DNA sequences. To put it simply, the number of generations with a specific DNA sequence for one gene is not large enough before it changes physically because of the given mutation rate for that very gene to allow us to speak of a specific selection pressure (codon-bias). This observation is at the heart of the so-called neutralism debate in genetics (see Nei 2005). However, this possibility (or fact if you prefer) doesn't block the theoretical possibility of constructing functionally defined sub-concepts that do not necessarily tell us what fitness contribution the gene in question *in fact* provides. The fitness index is dependent on the given environment anyway. Moreover, the sub-concepts articulate the *dispositions* for fitness contribution. These dispositions are inherently sensitive to physical differences by definition. In saying this, we are not only making the case for the metaphysical underpinning of reductionism; we are, as well, reflecting the contemporary debate on the understanding of fitness in terms of propensities or dispositions (see classically Mills & Beatty 1979; see also Weber 1996, Ariew & Lewontin 2004, Krimbas 2004, and Ariew & Ernst 2009 for clarifications and critical comments that, however, do not affect the main line of reasoning of this section: physical differences have, under certain environmental conditions, an impact on the biological level).

Biological research currently suggests that the differences in side effects, or effects that have no seemingly adaptive purpose, are not insulated from selection, but given changes in a physical environment, become the target of selection. Depending on changes in the physical environment (including the overall genetic makeup of the species population), certain DNA sequences may obtain a selective advantage over other DNA sequences because of possible differences in, for instance, the speed and accuracy of the production of the same proteins. It is easy to imagine adaptive scenarios in which the accurate and fast production of the membrane proteins in question may become important for the survival of the bacterium. Since fitness differences can theoretically be measured, biology has the means to consider them. Consequently, for any concept B defining a certain type of gene of *E. coli*, it is possible to conceive functional sub-concepts B_1 and B_2 taking into account these side effects (like the speed and accuracy of the protein production) by means of considering the resulting measurable fitness differences. Thus, once again simplifying in order to illustrate the idea, B_1 may be the conjunction of the gene tokens that express the protein in question (like all gene tokens coming under B) *and* the consideration of a certain time index of the protein production or the corresponding probabilities on fitness contributions, distinguishing it from gene tokens coming under B_2). This more precise rendering of sub-concept B_1 may be written as “ B and production of the characteristic effect X in t_1 ” or “ B and probability function C_1 of fitness contribution”, while the sub-concept B_2 may be something like “ B and production of the characteristic effect X in t_2 ” or “ B and probability function C_2 of fitness contribution” (see

Sachse 2007, chapter 4 to 7, for a detailed case study of the reduction of classical to molecular genetics along these lines).

Biology has the means to construct functionally defined sub-concepts and explanations that are nomologically coextensive with physical descriptions and explanations.



Physical concepts that constitute causal reductive explanations refer in a homogeneous way to the biological property tokens coming under one sub-concept.

To sum up the crucial point of this section, biology has the means to construct, *in theory*, functionally defined sub-concepts that are, as we shall discuss in more detail in the following section, nomologically coextensive with physical descriptions. Therefore, it is possible to apply our reasoning of the previous section to these sub-concepts: they are about causally efficacious property tokens (“*Cau*”) such that there is no danger of epiphenomenalism for biological tokens insofar as they are described by those sub-concepts.

4. The scientific quality of biology (“*Cau*” and “ \neg Rep”)

By means of these sub-concepts we attain concepts of biology that are nomologically coextensive with physical concepts and thus make it possible to reduce biology to physical theories in a functional manner, with three steps: 1) within an encompassing fundamental physical theory P , we construct the concepts P_1 , P_2 , etc. to capture the differences in composition among the local physical structures that are all described by the same concept B ; 2) B is more precisely articulated by constructing functional sub-concepts B_1 , B_2 , etc. of B , each of which captures the systematic side effects linked to the different ways of producing the effects that define B . To put it differently, the sub-concepts are constructed out of B in such a way that they are nomologically coextensive with the concepts P_1 , P_2 , etc. using the functional model of reduction shown in section 2; (3) B is reduced to P via B_1 , B_2 , etc. and P_1 , P_2 , etc. Reducing B (and thus biology) here means that starting from P , we can construct P_1 , P_2 , etc. and then deduce B_1 , B_2 , etc. from P_1 , P_2 , etc. given the nomological coextension. One derives B by *abstracting* from the conceptualization of the functional side effects contained in B_1 , B_2 , etc. for any environmental context where the functional side effects are not manifested or not pertinent to selection (see Esfeld & Sachse 2007).

The above-mentioned sub-concepts are not construed in a local or species-specific way that contains physical criteria, but in terms of purely functional differences only, say, different dispositions for fitness contributions. The functional sub-concepts B_1 and B_2 of B are distinct only by conceptualizing the different ways in which the effects that define B are or may be produced. Consequently, B always has the same substantial “specification of the function” in B_1, B_2 : these sub-concepts clearly express for biologists what their referents *functionally* have in common (the disposition *to* produce certain effects) and what their *functional* differences are (*the way in which* these effects are produced). To simplify, B is both a) an abstraction from certain dispositions, what we called side-effects in the genetic example and that are only brought out by the sub-concepts, and it is b) a focus on dispositions, call them pertinent similarities under certain environmental conditions, that are contained in the sub-concepts as well. For example, *E. coli* gene tokens falling under any sub-concept B_1, B_2 , etc. are biologically understood by taking into account fitness differences that are related to their expression of a certain protein, which means that our sub-concepts bring out salient causal similarities, the expression of the protein in question, and the laws relating to that effect. The concept B has the same substantial “specification of the function” in all these sub-concepts since the latter ones are constructed out of B . In any sub-concept, the disposition *to* produce the characteristic effect is contained as well. Therefore, this proposal does not put the scientific quality of the concept B and the laws in which it figures, couched in terms of B , in jeopardy, but on the contrary, justifies biology as a science by linking B and its laws in terms of B via its sub-concepts with physics.

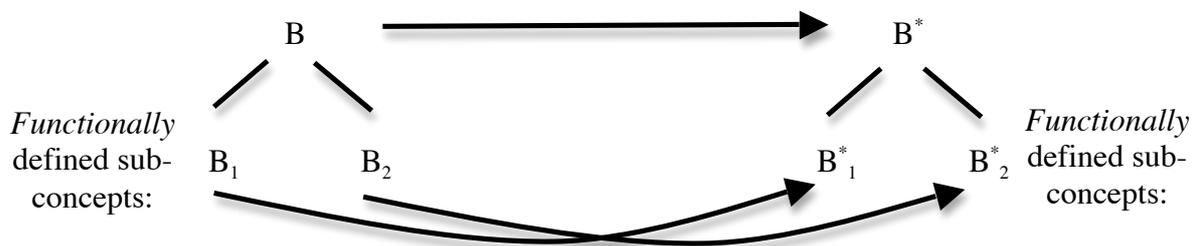
Let us see how we are now in the position to vindicate both “*Cau*” and “ $\neg Rep$ ” for B . On the basis of the fundamental physical laws, one can construct laws in terms of P_1, P_2 , etc. that refer to the properties on which biology focuses. From those laws, one can deduce biological laws in terms of B_1, B_2 , etc. given the nomological coextension of these concepts. These sub-concepts and any laws and explanations that are based on them are not about epiphenomena (thus vindicating “*Cau*”). Nonetheless, they were replaceable by physics because of nomological coextension (no vindication of “ $\neg Rep$ ”). However, one reaches the laws and explanations in terms of B by abstracting from the conceptualization of the functional side effects that are represented in B_1, B_2 , etc. Since the “specification of the function” of B is contained in each of its sub-concepts, the abstract concept B cannot be eliminated. The abstract laws of biology couched in terms of B are non-physical or not replaceable by physics in the sense that there is no single physical law having the same extension as any of these laws, vindicating “ $\neg Rep$ ” for B . The fundamental physical laws are too general, applying to everything that there is in the world, and the law-like generalizations couched in terms of those physical concepts that focus on the composition of the complex objects in question (the concepts P_1, P_2 , etc.) are too restricted. When talking about complex objects such as e.g. genes, cells, or whole organisms, the physical concepts focus on the composition of these objects. Due to selection there are salient causal similarities among effects that such complex objects produce as a whole, although they differ in composition. When we consider the concepts that capture these similarities, we don’t consider them as physical concepts, but – since they are relative to selection – take them to be concepts of biology.

Since in our world many environments are such that there is no differential selection for certain differences in composition among complex objects, being concerned only with the effects that these objects produce as a whole, the abstract concepts of biology possess a

scientific quality, figuring in law-like generalizations that capture something that is objectively there in the world. Nonetheless, these concepts and law-like generalizations do not conflict with the completeness of physics and the supervenience of everything on the physical, since, as we have shown, there is a reductive method to express them on the basis of the fundamental physical concepts and laws. The outcome of our argument thus vindicates the scientific quality of these biological concepts, without epiphenomenalism or eliminativism (see also my reconsideration of the status of abstract concepts in the context of biological functions in the following section).

One may sum up the essential point of this strategy as follows: the asymmetry that is spelled out by multiple realization is only a problem if this asymmetry is *all* that one can say about the relation between two different sciences. In addition to the still given asymmetry between the functionally defined abstract concepts (B) of biology and physical descriptions (P_1 and P_2), the proposed strategy establishes *symmetric* links in the form of nomological correlations between functionally defined sub-concepts (B_1 and B_2) of B and the physical descriptions (P_1 and P_2). It is in this sense that one may either call B to be “reducible” (via its sub-concepts) to physics, or call B to be “abstractable” from its sub-concepts (that are reducible to physics), depending on one's preferences.

One derives the original biological concepts *by abstracting* from functional side effects contained in the sub-concepts for any environmental context where these functional side effects are not manifested or not pertinent to selection.



The sub-concepts are constructed out of the original concepts and thus share the same meaning. Therefore, the abstract concepts are also about causally efficacious property tokens even though not replaceable by physical descriptions.

Regardless of our terminological preference, my general argument establishes the scientific quality of the descriptions of biology only insofar as selection is concerned. Since selection is widely acknowledged to be the reason why there is multiple realization at all (Papineau 1993, ch. 2), it follows that the approach can be applied to any other biological branch as well. The argument can be summed up as follows: a) classical reductionism is considered to be refuted by the thesis of multiple realization. Multiple realization is supposed to be based upon natural selection; b), our proposed conservative reductionist strategy derives from our acceptance of multiple realization, and of its basis. It should now be clear why neo-Darwinian evolution is the reason why there seems to be a problem for reductionism, as well as why we believed, given the construal of selection that we proposed to outline, we could nevertheless reduce biology with an alternative strategy.

Let me be clear on the second crucial ingredient of this alternative strategy. This proposal to establish a systematic link between biology and physics via functional sub-concepts presupposes the causal-functional theory of properties (see Michael Esfeld's contribution to this volume). If the fundamental properties were pure qualities, so that what they are is independent of the causal relations in which objects stand in virtue of having these properties, then any causal-functional description of biology could trivially be multiply realized by replacing pure qualities of one type with pure qualities of another type. In this schema, there would be no causal difference effected by that substitution (see also Jackson 1998, pp. 23-24). By the same token, this proposal presupposes the anti-Humean view of the laws of nature being metaphysically necessary that goes with the causal theory of properties: otherwise, the same biological laws could be reached from different sets of fundamental physical laws that are obtained by changes in the distribution of the fundamental physical, purely qualitative properties. Consequently, there would no longer be one single fundamental physical theory – or one coherent set of fundamental physical theories – to which biological theories could in principle be reduced. With my premises, then, in place, I showed, on the basis of all properties being causal-functional ones, that the proposed reductionist strategy is indeed able to show how both biological theories and their target entities are related to fundamental physics down to their specific characteristics.

5. *Perspectives for other debates in the philosophy of biology*

What is the utility of reductionism? The specific character of biology has posed a dilemma for the philosophy of science, in as much as science is considered to be unified. Conservative reduction redeems biology for a united science by showing how its discourse can be linked to physics and thus avoids primarily metaphysical conflicts. By adopting the proposed reductionist strategy, we block the danger of epiphenomenalism or eliminativism as the ultimate philosophical framework for abstract biological concepts, laws and explanations. In addition, conservative reductionism may constitute a plausible framework for approaches that normally have an anti-reductionist background. For instance, it is possible to take those explanations of biology that have no coextensive counterpart in physics as *unifying* explanations in Philip Kitcher's sense (Kitcher 1976 and 1981). By abstracting from physical differences, one and the same biological concept, explanation and law applies to physically different entities. It then seems that Kitcher's arguments in favour of the scientific quality of classical genetics (and of biology in general) can now be grounded within or made compatible with the proposed conservative reductionist framework (compare Kitcher 1984 with the strategy outlined above). Following this reasoning, fitness, natural selection, genes, etc. can be understood as concepts with a high degree of abstraction, which lead to unifying biological explanations that have no coextensive equivalent in physics. Keep in mind that the given degree of abstraction is based on how the world actually is and evolves and whether certain physical difference may or may not imply functional differences that have to be taken into account.

The reductionist strategy constitutes hence an explicit argument to take the principle of natural selection and other biological generalizations as law-like (see also Rosenberg 2001, 2006, ch. 4 and Sober 2000, ch 1.4). In order to show this point, the concepts that constitute

the principle of natural selection (or any other biological generalization) only have to be theoretically connectable via sub-concepts with physical descriptions and laws. Biological generalizations that are couched in terms of sub-concepts get their law-like character from physics deductively, on account of nomological coextension. From this move, abstract biological generalizations inherit their law-likeness, since they only abstract from certain functional details, which is, depending on the context, scientifically justified if coherent explanations can still be provided. Through this argument, the principle of natural selection appears to be the most abstract and unifying law-like generalization of biology that is, by means of its application to specific units of selection, connected to physics.

Following this conclusion, we can then specify the difference between so-called proximate and ultimate explanations in a particular way. Using Sober's question "Why do ivy plants grow toward the sunlight?", there are two possible answers that characterize proximate and ultimate explanations respectively (see Sober 2000, ch. 1.2): an answer that is couched in terms of the physiological mechanisms that programme the plant to engage in phototropism is a proximate explanation, which refers to ontogenetic causes and provide mechanistic explanations. Alternatively, one may outline the phylogenetic causes and explain the capacity of phototropism in relation to adaptation and selective advantage. Postulating an evolutionary lineage that begins with the first organisms (so to speak) that possessed this trait, we can outline via genetic transmission from generation to generation (or across species boundaries due to lateral gene transfer or hybridisation) a clear causal relation between the ivy and its place in the timeline of natural selection on which an explanation of the adaptive purpose of phototropism can be based.

In the context of the reductionist approach, the difference between both explanations can be spelled out as difference in degrees of abstraction. The proximal explanation refers to local processes that occur in each generation again and again, and since a fitness contribution is thus implied, one may, by summing up and abstracting from several details, end up with ultimate explanations. Thereby, it depends on the given and changing environmental conditions what kind or degree of abstraction is justified. To put it differently, the reductionist approach constitutes a hierarchical system of concepts, laws and explanations and thereby shows how ultimate explanations are related to proximal explanations.

Against this background, one may also elaborate on a similar debate – about the different approaches to the very notion of biological functions. Let us consider for instance the two most current approaches – the etiological one that determines biological functions generally as selected effects, thus, by a reference to the evolutionary past (see also Millikan 1989, Neander 1991, Griffiths 1993, Mitchell 1993, Godfrey & Smith 1993 and 1994, and Schwarz 1999) and the systemic or causal-dispositional approach that defines biological functions without such a reference to the evolutionary past (see also Bigelow & Pargetter 1987, Amundson & Lauder 1994, Manning 1997, Weber 2005 ch. 2.4 and Mossio et al. 2009; see furthermore Kitcher 1993 and Arp 2007 for some kind of compatibility of these approaches). Without going into the details of these approaches – since it is beyond the scope of this paper to add any new argument or counterarguments at this point – one may take the proposed approaches as differing mainly in their extension and thus explanatory force.

While the etiological approach refers to past occurrences and thus mainly to manifested and pertinent dispositions and therefore is somehow similar to ultimate explanations based on phylogeny, the systemic and causal-dispositional approach sticks more to local causal

capacities of systems or dispositions and thus can be identified with ontogenetic mechanistic explanations. By adopting a reductionist perspective according to the outlined strategy – that the etiological approach is a more abstract approach or concept of biological functions than the other one but nonetheless reducible to it – one may explain away the main difficulties and make more explicit the advantages of both approaches. Thereby, once again, it depends on the given and changing environmental conditions whether the more abstract approach is justified. To put it differently, it is the environment that constitutes the normative aspect for any kind of functional ascription. If, for instance, minor physical differences have an impact on the function under the given environmental conditions, there is an argument to account for this fact and this is, in the most extreme case, done by the construction of functional sub-types in terms of causal dispositions. By contrast, many physical differences have no functional impact under certain environmental conditions such that more abstract approaches, even with a historical dimension, are admitted or even preferred to provide more unifying explanations.

What I have proposed with respect to the debate on biological functions and on biological concepts, laws and explanations of different possible degrees of abstraction applies as well to the debate on biological taxa being natural kinds (see for the debate among others Brigandt 2003 and 2009, Dupré 1981, Ereshefsky 2007 and 2010, LaPorte 2004, Mallet 2010, O'Malley 2010, and Richards 2008). Conservative reductionism supports a realist attitude with respect to biological kinds in the following general way: since the sub-concepts are nomologically coextensive with physical descriptions, it is possible to apply any argument in favour of (composed) physical kinds being natural ones to the biological sub-concepts as well. Thus, the more abstract biological concepts inherit their naturalness and counterfactual robustness from their sub-concepts, or, to put it differently, the reductionist framework makes explicit the hierarchical structure of a system of natural biological kinds that is *theoretically* achievable. Additionally, depending on the given and changing environmental conditions, the abstract biological concepts such as biological taxa can figure in biological laws and explanations. Thereby, neither inheritance nor the biological sphere's systematic hierarchical structure contains, in the ideal case, any conventionalist aspect.

Still, biological species are evolving while physical natural kinds are not and, from a biological perspective, evolution contains some kind of contingency. This suggests to understand biological species rather as individuals than genuine kinds with real essences. However, sub-concepts do not contain more contingency than (composed) physical kinds to which they are nomologically coextensive. Furthermore, there is no principal difference whether we consider multiple realization of a type at one specific time or for a period of time. For instance, imagine an abstract concept B_{t_1} that applies to any member of a species at t_1 and this concept can be conservatively reduced via its sub-concepts to physics. Look at that species at a later stage in evolution (at t_2) and imagine once again that an abstract concept B_{t_2} applies to any member of a species and this concept can be conservatively reduced via its sub-concepts to physics as well. If we now compare both abstract concepts B_{t_1} and B_{t_2} , it is likely that they differ somehow and it is even more likely that their sub-concepts differ somehow since evolution has taken place. However, there is no principal objections that both abstract concepts B_{t_1} and B_{t_2} may constitute themselves two sub-concepts for some more abstract concept that bring out salient characteristic similarities that figure in explanations. Call this a theoretical species concept that applies to B_{t_1} and B_{t_2} .

It is out of the scope of this paper to discuss this approach and seemingly problematic issues like speciation in detail. However, whether physical differences give rise to speciation depends on the given context. Within the framework of conservative reductionism it thus is suggested that differences in essence in combination with the given environmental conditions constitute or not the starting point for speciation. In other terms, phylogenesis during evolution does not depend on us but on the world and the underlying physical structures and changes that can be, in theory, considered in terms of sub-concepts and more abstract concepts. On that theoretical basis, classifications that mostly focus on a historical dimension like common ancestry and that may exclude real essences *do not hinder* to construct biological kinds ahistorically with genuine essences. Here as well evolution gives us an impressive idea what kind of biological species were and actually are realized.

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