Marrying the merits of Nagelian reduction and functional reduction

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Abstract

This paper points out the merit of Nagelian reduction, namely to propose a model of inter-theoretic reduction that retains the scientific quality of the reduced theory, and the merit of functional reduction, namely to take multiple realization into account and to offer reductive explanations. By considering Lewis' and Kim's proposal for local reductions, we establish that functional reduction fails to achieve a theory reduction and cannot retain the scientific quality of the reduced theory. We improve on that proposal by showing how one can build functional sub-types that are coextensive with physical realizer types and thereby obtain a theory reduction that is explanatory and that vindicates the scientific quality of the special sciences.

Keywords: bridge principles, functional reduction, multiple realization, Nagelian reduction, theory reduction

1. The motivation for Nagelian reduction

Consider a theory T_1 of a special science with a limited domain of application such as, for instance, classical genetics or folk psychology. Assume that T_1 is true or approximately true, that its concepts seize natural kinds, that it contains laws or law-like generalizations, which capture salient causal connections in the world, that it has ample predictive success, etc. – in short, let T_1 be a mature scientific theory. We wonder how T_1 fits into our broader body of knowledge. We have no inclination to suppose that T_1 is about properties – and connections between properties – that do not strongly supervene on more basic physical properties. Let us therefore assume that there is a more basic theory T_2 with a broader domain of application that includes the domain of objects to which T_1 refers, such as, for instance, a theory of molecular biology or physics. Since the domain of objects of T_1 is a proper part of the domain of objects of T_2 and since the properties with which T_1 is concerned strongly supervene on the properties with which T_2 is concerned, there has to be a systematic relationship between T_1 and T_2, including a systematic relationship between the laws of T_1 and the laws of T_2 (given that the manner in which the properties in the focus of T_1 are connected with each other, as captured by the laws of T_1, strongly supervenes on the manner in which the properties in the focus of T_2 are connected with each other, as captured by the laws of T_2).

The reducibility of T_1 to T_2 is the primary candidate for such a systematic relationship. If the properties in the domain of T_1 strongly supervene on the properties in the domain of T_2, then all the truths about the properties in the domain of T_1 are derivable from the truths about the properties in the domain of T_2. This is not to say that they are *a priori* derivable; the deduction may need principles that are established only *a posteriori*. In the following, we briefly recall the Nagelian model of deriving the laws of T_1 from the laws of T_2 and thus the reduction of T_1 to T_2 (this section). We then point out how the Nagelian account of theory reduction fails due to multiple realization and how Lewis' and Kim's model of functional reduction takes multiple realization into account. However, that model falls short of a theory reduction; it ends up in the elimination of T_1 rather than its reduction to T_2 (section 2). Against this background, the rationale of this paper is to show a way to develop functional reduction into a model of a fully-fledged, conservative theory reduction, thereby marrying the merits of Nagelian reduction and functional reduction (section 3).

In order to be in the position to derive the laws of T_1 from the laws of T_2, it is necessary to have concepts proper to T_2 and figuring in the laws of T_2 at one's disposal that cover the extension of the concepts proper to T_1 and figuring in the laws of T_1. The issue is only about extension: the meaning (intension) of the concepts of T_1 can remain unrelated to the meaning (intension) of the concepts of T_2. For instance, one can master the concepts "gene", "phenotypic effects", "heredity", etc. and make reliable predictions in terms of these concepts without understanding the meaning of the concepts "DNA", "protein synthesis", "DNA polymerase", etc. and thus without having any idea about molecular biology. But if one wishes to derive what classical genetics tells us about genes from molecular biology (or physics), then one needs a proper molecular concept figuring in laws of molecular biology that covers the extension of the concept "gene", the concept of "DNA" being a suitable candidate for such a concept for the purposes of this paper.

Covering the extension does not necessarily imply coextension, since the domain of application of T_2 – and thus the domain of application of its laws – is usually broader than the domain of application of T_1. But, leaving aside the issue of multiple realization, this is not a problem: it is logically possible to build within T_2 concepts in the vocabulary proper to T_2 that are tailor-made for the domain of application of the concepts proper to T_1 and formulate the laws of T_2 in terms of these tailor-made concepts, insofar as these laws are relevant to the proper part of the domain of application of T_2 that is identical with the domain of application of T_1. Assume that the concept "gene" covers only that part of the extension of the concept "DNA" of molecular biology in which DNA sequences are replicated and cause observable effects like the colour of blossoms. It is then possible to build concepts of molecular genetics (T_2) that focus only on such effects of DNA sequences. On that basis, one may furthermore formulate laws in which these more restricted concepts figure (insofar as these laws apply only to particular effects of DNA sequences). The important point is that for each concept proper to T_1, one needs one concept proper to T_2 and suitable to figure in the laws of T_2 that covers the extension of the concept proper to T_1 in question.

We thus get to the two conditions both necessary and together sufficient that the textbook accounts of Nagelian reduction, going back to Nagel (1961, chapter 11) pose: in order to reduce T_1 to T_2, one has (a) to build for each concept F proper to T_1 and figuring in the laws of T_1 a concept P in T_2 suitable to figure in the laws of T_2 that is coextensive with F so that the following biconditional holds:

(1) $\forall x\,(F\mathrm{x} \Leftrightarrow P\mathrm{x})$

Furthermore, (b) one has to deduce the laws of T_1 from the laws of T_2 by means of such biconditionals. These bridge principles in the form of biconditionals are not themselves laws of nature, since they relate only the concepts of different theories, without necessarily telling us anything new about nature (see also Kim 2008, section II). But they have to be nomologically necessary in the following sense: in any possible world in which the laws of T_1 and the laws of T_2 hold, these biconditionals are also valid.

In Nagelian reduction, there is no question of T_1 being eliminated as a result of its reduction to T_2. If the no miracles argument is a good argument for scientific realism, that argument applies not only to the more fundamental theory T_2, but also to the special science theory T_1, since T_1 (e.g. classical genetics, or folk psychology) includes a wide range of successful predictions. *The central merit of Nagelian reduction is that it is a model of theory reduction that permits to retain both T_1 and T_2 as part of our system of scientific knowledge.*

2. *The motivation for functional reduction and its limits*

Multiple realization is the main objection against Nagelian reduction and inter-theoretic reduction in general. Even if the properties in the domain of T_1 strongly supervene on the properties in the domain of T_2, this does not imply that we can achieve biconditional links between the concepts proper to T_1 and concepts belonging to T_2. Strong supervenience is compatible with multiple realization. The properties in the domain of T_1 can be multiply realized by property configurations of different types in the domain of T_2. Consequently, one cannot infer from the properties that are given in a certain situation, coming under T_1, which (subvenient) property configurations there are, coming under T_2. Therefore, multiple realization implies the failure of Nagelian reduction as it stands.

However, there is a form of reduction compatible with multiple realization, namely functional reduction as proposed notably by Lewis (1972, 1980 and 1994) and taken up and further developed by Kim (1998 and 2005). Functional reduction proceeds in three steps:

1) One defines the property types in the domain of T_1 in a functional manner by indicating notably their characteristic effects in terms of T_1 – to put it differently, the causal roles that tokens of these property types exercise.

2) One looks for realizers of these causal roles in the domain of the properties of T_2. The realizers of the functionally defined properties may differ physically.

3) One explains in each case – that is, for each token (and thus independently of whether or not multiple realization obtains) – why there is a functional property falling in the domain of T_1 by describing how a configuration of properties in the domain of T_2 present in the situation under consideration brings about the effects that are characteristic of the functional property type in the domain of T_1 in question.

For instance, classical genetics defines genes in a functional way. Genes encode genetic information for the production of phenotypic effects that can be transmitted from generation to generation (1). The specific causal roles of genes are realized by molecular configurations, namely certain DNA sequences, though often molecularly different ones, in most known organisms (2). Molecular biology can explain how such configurations – notably certain DNA sequences – are copied and transmitted to the next generation and how they bring about the effects that are pointed out in the functional definitions of classical genetics (3).

Functional reduction hence offers in each case, even if there is multiple realization, a causal explanation of why there is a property token present falling in the domain of T_1 by telling us how the effects that are characteristic of the property type in question are brought about (cf. what Chalmers 1996, pp. 42-51, calls a reductive explanation). Functional reduction thereby explains why there are properties falling in the domain of T_1 in the world and thus shows how T_1 is about salient properties. More precisely, the explanation in question is a mechanistic one in the sense of Machamer, Darden and Craver (2000), revealing a mechanism that brings about the effects characteristic of a certain property type in the domain of T_1 (see also Kim 2008).

In order to provide such reductive explanations, functional reduction has to rely on some sort of bridge principles in its step 2 as well (see Endicott 1998, section 8, Hüttemann 2004, chapter 4.3, Marras 2005, pp. 344-347, Fazekas 2009; but see also Morris 2009 against this claim). The reason is that the definition of the property types in the domain of T_1 (step 1) including the description of their characteristic effects is carried out in the concepts proper to T_1. By contrast, all the properties in the domain of T_2 and their effects are described in the concepts proper to T_2. Hence, in order to be in the position to discern in step 2 a certain configuration of properties in the domain of T_2 as a realizer of a property type in the domain of T_1, one has to create a link between concepts proper to T_2 and concepts proper to T_1. This link is generally established on the basis of identifying the effects brought about by a certain property in the domain of T_1 in a given situation with effects brought about by a configuration of a certain type in the domain of T_2 in that situation.

To put it differently, the identification of realizer types does not presuppose *biconditional* bridge principles but is based on the common effects of properties of T_1 and configurations of properties of T_2. For instance, molecular biology can identify DNA sequences as those configurations that lead to the characteristic effects of genes (as defined by classical genetics) even though gene tokens of one single type may differ molecularly. Given that multiple realization does not hinder the discovery of realizer types (step 2), it is possible to provide, in terms of T_2, reductive explanations (step 3) of why there are properties coming under T_1 in the world. Thus, molecular biology explains why genes have their characteristic effects (defined by classical genetics, step 1) by outlining the mechanisms of how certain DNA sequences (step 2) lead to, for instance, the synthesis of proteins that bring about the phenotypic effects in question, given normal conditions in the organism and its environment.

To put the matter more formally, one-way conditionals describing a property or configuration of properties of a certain type in the domain of T_2 as a realizer of a property type in the domain of T_1 are sufficient for reductive explanations. Let F be a concept proper to T_1, seizing properties of a certain type in the domain of T_1, and let P_1 be a concept proper to T_2, seizing properties of a certain type in the domain of T_2, being a realizer of F. In singling out a token x coming under P_1 as a realizer of F, thus coming also under the concept F in T_1, one takes for granted a bridge principle of the following form:

$$(2)\ \forall x\,(P_1x \rightarrow Fx)$$

Strong supervenience assures us that this connection is at least nomologically necessary, if not metaphysically necessary: if the concept P_1 in T_2 describes a supervenience base for tokens that are described in terms of the concept F in T_1 and thus expresses a sufficient condition for there being tokens that can be described in terms of F in T_1, then whenever there is a configuration of the type P_1 in the domain of T_2, there is a token of F in the domain of T_1. However, the reverse conditional does not hold:

(3) $\forall x\ (Fx \rightarrow P_1x)$ is false.

Due to multiple realization, there may be configurations of the type P_2 in the domain of T_2 that also realize F. Consequently, the following one-way conditional holds also with nomological necessity:

(4) $\forall x\ (P_2x \rightarrow Fx)$

Hence, bridge principles in the form of such one-way conditionals are sufficient for assuring that for each property token coming under F in T_1, there is the possibility of a reductive explanation of that token in terms of concepts that are proper to T_2 (P_1 or P_2, etc.). The possibility of such a reductive explanation is secured by the functional character of this model of reduction: assuming the strong supervenience of higher-level properties on lower-level properties, the lower-level descriptions P_1 and P_2 grasp the causal properties that in turn explain how the causal role defining F is brought about in each case.

Though one-way conditionals are sufficient for the discovery of realizer types and reductive explanations, one-way conditionals are not sufficient for reducing T_1 to T_2, even if the domain of objects of T_1 is a proper part of the domain of objects of T_2 (T_2 may be a fundamental and universal physical theory). The reason is that one cannot deduce the laws of T_1 from the laws of T_2: there are no concepts available in T_2 that are coextensive with the concepts proper to T_1 and in which the laws of T_2 can be formulated, insofar as they are pertinent for that part of the domain of objects of T_2 that is identical with the domain of objects of T_1. Consequently, one cannot deduce the laws of T_1 from laws of T_2: the concepts figuring in fundamental and universal laws of nature (such as e.g. the laws of gravity or electromagnetism) are too general in order to deduce the laws of T_1 from these laws, and the concepts proper to T_2 that seize particular realizer types of property types of T_1 and laws or law-like generalizations formulated in terms of these concepts are too specific to capture the property types on which T_1 focuses: if there is multiple realization, several concepts proper to T_2 are needed to cover the extension of a single concept proper to T_1.

Nonetheless, Lewis and Kim propose a middle way between reductive explanations of individual tokens and a fully-fledged theory reduction. That middle way, known as *local reduction*, is based on considering groups in which a property type of T_1 is not multiply realized. Let us consider an artificial example: assume for the sake of the argument that pain is a functional property type in which folk psychology (T_1) trades. Suppose that if and only if a human being suffers pain, c-fibres in the human brain are stimulated. Suppose furthermore that if and only if an octopus suffers pain, b-fibres in the brain of the octopus are stimulated. In this case, as far as the human species is concerned, the functional concept "suffers pain" is coextensive with the neurobiological concept "c-fibres are stimulated". Furthermore, as far as the species octopus is concerned, the functional concept "suffers pain" is coextensive with the neurobiological concept "b-fibres are stimulated". Consequently, the psychological, functional theory about pain can be reduced to the neurobiological theory about c-fibres in the case of the human species, and it can be reduced to the neurobiological theory about b-fibres in the case of the species octopus. We thus need one reducing theory for each realizer type of a given property type of T_1 (see Lewis 1969, 1980 and Kim 1998, in particular pp. 93-95, and 2005, in particular p. 25).

The theory T_1 thus is split into several theories T_{1a}, T_{1b}, T_{1c}, etc, which are in turn reduced to several theories T_{2a}, T_{2b}, T_{2c}, etc. corresponding to the various realizer types of the property types in which T_1 trades. The crucial move in order to achieve such local reductions, limited to one specific group of realizers, is the replacement of each multiply realized property type or concept proper to T_1 with several hybrid types or concepts that are relative to particular groups in which there is uniform realization – such as "pain-in-humans", or "pain-in-octopus", etc. These latter concepts are then coextensive with the concepts of a reducing theory each – "pain-in-humans" is coextensive with "c-fibres are stimulated", "pain-in-octopus" is coextensive with "b-fibres are stimulated", etc. However, these hybrid concepts are not concepts proper to T_1: they cannot be construed in the vocabulary of T_1 alone.

The original concepts of T_1 are functionally individuated. This means that all the property tokens coming under the concept *F* proper to T_1 are causally identical from the point of view of T_1. However, given multiple realization, these property tokens supervene on configurations of physical property tokens that are different from the point of view of T_2 and that are consequently causally heterogeneous. If these configurations of physical property tokens were not causally heterogeneous, there would be no reason to assume that they belong to different physical types. The problem then is that the patterns of causal regularities that are grasped by T_1 are invisible from the point of view of T_2. Consequently, the possibility to account, within T_2, for the ability of T_1 to grasp salient patterns of regularities gets lost.

The introduction of hybrid group-specific concepts such as "*F* in group S_1", "*F* in group S_2", etc., cannot alleviate this consequence. These concepts cannot help to make the ability of T_1 to grasp causal regularities that are invisible from the perspective of T_2 intelligible. Introducing hybrid group-specific concepts or types simply shifts the problem raised by multiple realization from the relationship between the types of T_1 and the types of T_2 to the one obtaining between the types of T_1 and these new hybrid types or concepts. By way of consequence, the homogeneous pattern or natural kind that T_1 seizes by forming a concept *F* gets lost in this proposal. The uniform type in which T_1 trades by building a concept *F* is split into group-specific types, whereby the conjunction of these groups does not have anything in particular in common from the physical point of view that defines these groups. It is therefore not possible to retrieve on the basis of concepts such as "*F* in group S_1", "*F* in group S_2", etc. a significant common content "*F*", seizing a homogeneous pattern or natural kind in the world. "*F*" means something different in S_1, S_2, etc. This account thereby fails to achieve a key goal of inter-theoretic reduction, namely to explain how higher-level theories are able to provide homogeneous causal explanations of phenomena that are heterogeneous from the physical point of view. One therefore ends up in eliminating the functional types *F* of T_1, as Kim himself concedes:

> Unless two realizers of *E* show significant causal/nomological diversity, there is no clear reason why we should count them as two, not one. It follows then that multiply realizable properties are ipso facto causally and nomologically heterogeneous. This is especially obvious when one reflects on the causal inheritance principle. All this points to the inescapable conclusion that *E*, because of its causal/nomic heterogeneity, is unfit to figure in laws, and is thereby disqualified

> as a useful scientific property. … The conclusion, therefore, has to be this: as a significant scientific property, *E* has been reduced – eliminatively. (Kim 1999, pp. 17-18)

E stands here for any functional property type of a special science that is not identical with a physical property type. This conclusion, however, is devastating for the project of group-specific reductions: instead of improving on reductive explanations of individual tokens, going half the way towards a theory reduction, the basis for such reductive explanations is in fact undermined, if the concepts or property types *F* on which T_1 focuses itself are de facto eliminated. In a later paper, Kim urges us to abandon the property types *F* in which T_1 trades as genuine, unitary types (natural kinds); he nevertheless proposes to retain the concepts proper to T_1, but only as conventions to which no natural kinds, patterns or pertinent similarities in nature correspond (Kim 2008, pp. 108-112). Thus again, we have to eliminate the concepts proper to T_1 as classifications that possess a scientific quality.

In this manner, the proposal of a group-specific theory reduction of Lewis and Kim collapses in fact into the conception known as new wave reductionism (Bickle 1998, 2003) that goes back to Hooker (1981, in particular p. 49). According to this latter conception, one constructs within the vocabulary of an encompassing physical theory T_2 a specific reducing theory T_{2a}, T_{2b},T_{2c}, etc. for each realizer group of the functional property types *F* in which a theory T_1 of a special science trades. These group specific theories formulated in terms of the concepts proper to T_2 then replace T_1.

Let us sum up. Given the fact that we have universal and fundamental physical theories at our disposal, eliminating the scientific quality of the theories of the special sciences and retaining the kinds in which these theories trade only for heuristic and practical purposes is an answer to the question of the unity of science that is easily available, but unsatisfactory. Many of the theories of the special sciences are mature theories by all standards, having ample predictive success. If one regards the no miracles argument as a good argument for scientific realism, one has to take into account the fact that this argument applies not only to fundamental physics up to molecular chemistry, but also to many theories of the special sciences. In what follows, we therefore set out to improve on the functional model of reduction in order to show how it is possible to vindicate the scientific quality of the special sciences. As we shall demonstrate, the special sciences grasp objective patterns of similarities, which cannot be grasped by fundamental theories, and they have consequently a legitimate status in our body of scientific knowledge rather than simply a heuristic role. The outcome of our development will be a proposal for a conservative strategy of functional reduction that does not suffer from the eliminativist consequences of Kim's model or new wave reductionism.

3. *The need for biconditionals and how to obtain them*

If there is multiple realization, then it is not possible to build types or concepts within a reducing theory T_2 that are coextensive with the types or concepts in which T_1 trades and that seize, if T_1 is a mature theory with ample predictive success, natural kinds or at least objective patterns of similarities that exist in the world. Nonetheless, there are reductive explanations of any token of a property type of T_1 in terms of T_2 possible, based on one-way conditionals from concepts proper to T_2 to concepts proper to T_1. However, such reductive explanations cannot stand on their own, for they leave the homogeneous patterns that T_1 highlights unconnected to the types and concepts in which T_2 trades. Lewis' and Kim's conception of a local, group-specific reduction does not improve on this situation, leading on the contrary to an elimination of the types and concepts proper to T_1 from mature science. The conclusion hence is that we have to relate the types or concepts that are proper to T_1 to the types or concepts proper to T_2, and we need biconditionals (coextensive types or concepts) to do so. Lewis' and Kim's conception is therefore on the right track insofar as it seeks to obtain on the basis of the types or concepts in which T_1 trades more specific types or concepts that are coextensive with types or concepts proper to T_2. The problem is that Lewis and Kim do so by using criteria from T_2 that are foreign to T_1 so that the unity of the types or concepts of T_1 gets lost by being relativized to certain groups that are defined in terms of T_2. By contrast, we shall show in this section how one can obtain more fine-grained *functional* sub-types of the types in which T_1 trades that are coextensive with types that can be built in T_2, but that are construed by relying *only* on the conceptual means of T_1.

If there are different types of realizers P_1, P_2, P_3, etc., described by T_2, of a property type F of T_1, then these realizer types differ not only in their molecular composition, but also in their causal dispositions. If the differences in composition did not imply causal differences, we would not be in the position to establish that the realizers of F come under different physical types. In order to be in the position to detect differences between them, these differences have to imply the disposition to react differently in interactions with measuring instruments. The claim that differences in composition imply causal differences holds not only if one subscribes to a version of what is known as the causal theory of properties according to which the causal role is essential to a property so that in all the possible worlds in which there are properties of the type P, these properties play the same role in each world (see e.g. Shoemaker 1980); this claim also holds in a Humean theory of categorical properties, being pure qualities whose essence is a quiddity and that exercise different causal roles in different possible worlds depending on the whole distribution of the fundamental properties in a given world: as far as the relationship between the functional property types in which the special sciences trade and the types of physical realizer properties is concerned, whenever there are different physical realizer types of a given property type F of a special science in the world, there are, against the background of the whole distribution of the physical properties in the actual world, differences in the causal relations in which tokens of these physical property types stand – such as differences in the interaction with measuring instruments. It is only that these physical property types are themselves multiply realized by pure qualities of different types, and we cannot detect these latter differences (that consequence is known as humility; see e.g. Lewis 2009).

Independently of the metaphysics of properties to which one subscribes, one thus has to acknowledge that differences in composition, accounting for there being realizers of different physical types of a given property type F of a special science in the actual world, imply causal differences. Note that not any odd difference in composition between two tokens of a realizer of F amounts to there being two different *types* of realizers of F and thus a case of multiple realization. To get multiple realization in a non-trivial sense, the differences in composition have to concern the way in which F, being defined in a causal manner by certain characteristic effects, is realized. In other words, differences in composition between two or more realizer *tokens* of F amount to there being two or more realizer *types* of F if and only if these differences concern the components of the mechanism by means of which each realizer brings about the effects that characterize F. Against the background of the fact that differences in composition imply causal differences on any theory of properties, one thus filters out the causal differences that account for there being two or more realizers types of *F* by demanding that the causal differences concern the way by means of which the effects that characterize *F* are brought about.

Such causal differences are not limited to the way or mechanism that brings about the effects that characterize *F*, leading always to identical effects such that these differences cannot be detected by employing the conceptual means of the theory in which *F* is embedded, that is, T_1. As already mentioned, whenever there are differences in composition, these differences can be detected only if they imply causal differences in the reaction with measuring instruments. *A fortiori*, differences in composition that imply different mechanisms or ways to bring about the effects that characterize *F* and that thereby amount to there being different types of realizers of *F* lead to differences in the interaction with measurement devices. Such differences are macroscopic differences that can be observed with the naked eye and can thus be expressed by the conceptual means of common sense. Against that background, one can easily conceive experimental conditions such that differences in the way in which the effects that characterize *F* are brought about lead to causal differences that can be detected and expressed within the framework of T_1, although that conceptual framework may not be sufficient to explain why such differences occur.

There is nothing particular about measuring instruments and measuring interactions. These are by no means natural kinds – such as gravitational or electromagnetic interaction, and accordingly mass and charge. There is no physical definition of what constitutes a measuring interaction and a measurement device. In the present context and for the purposes of this paper, we can therefore simply talk in terms of the more general notion of environmental context. In certain environmental contexts – which can be artificially created in a laboratory, but which can also obtain in nature without human intervention –, the differences in the ways in which the effects that characterize *F* are brought about, accounting for there being two types of realizers of *F*, lead to differences in these effects themselves that can be detected on the level of description of T_1, although presumably not be explained on that level.

The following reasoning adds further support to the claim that, even without human intervention, differences in realization entail differences that are salient at the level of description of T_1. Consider a possible world w_1 at t_0 which is identical to the actual world in any respect and another possible world w_2 at t_0 which is also exactly alike the actual world from the point of view of T_1 but in which there is no multiple realization: any property token of T_1 is realized in w_2 by the same type of configuration from the point of view of T_2. It is clear that in such circumstances, w_1 and w_2 are not distinguishable from the point of view of T_1 at t_0. However, it seems reasonable to assume that after a certain length of time, at t_{0+n}, both worlds will nonetheless be distinguishable from the point of view of T_1 as well. In w_2, entities coming under a concept proper to T_1 fulfil, due to their physical differences, slightly different causal roles. These differences lead over time to differences with respect to the causal evolution of w_1 that are likely to be important enough to end up in differences that are observable using the descriptive resources of T_1.

This example assumes that at some point of time, a divergence within the respective distributions of property tokens described by T_1 in w_1 and w_2 will occur. It means that at this point of time, an entity coming under a certain concept *F* in T_1 and a physical concept P_1 in w_1 and its counterpart in w_2, coming also under *F* but under P_2 instead of P_1, will react to their environment in a way that is sufficiently dissimilar to give rise to a difference between both worlds that can be grasped by using only the conceptual resources of T_1. There are hence environmental circumstances in which differences in realization lead to functional differences as well.

Let us illustrate these claims by drawing on classical genetics. Multiple realization in this field of research is an empirical fact that is not astonishing, since the approach of classical genetics is more abstract than the one of molecular genetics. Natural selection explains why there is multiple realization in the domain of classical genetics (see Papineau 1993, p. 47, and also Rosenberg 2001): depending on the environmental conditions, only some of the causal powers of a given molecular configuration, realizing a property of the type F of classical genetics, are pertinent for selection. Against this background, it is reasonable that the proper concepts of classical genetics abstract from molecular differences. There are for instance molecular differences among DNA sequences possible that, under certain cellular conditions, do not amount to phenotypic (functional) differences.

These molecular differences, as already mentioned, are different ways to bring about the effects that define F. There then is at least one difference in the production of side effects that are systematically linked with the main effects in question – such as different causal interactions with the molecular environment within the cell during the causal process from a gene to the production of its characteristic phenotypic effects. For any such difference in side effects, there is a molecular environment possible in which that difference leads to a detectable functional difference within the scope of classical genetics and the evolutionary context because any such difference may become pertinent to selection in certain environments (see Rosenberg 1994, p. 32). Consequently, that difference can in principle also be considered in terms of the concepts that are proper to classical genetics. One can thus, for instance, introduce more precise functional definitions that take into account different reaction norms that are linked to the molecular differences. A reaction norm is a function defining the different probabilities of fitness contributions of a gene relative to different environments. Against this background, for any type F of T_1 (that is multiply realized by P_1, P_2, etc.), it is possible to conceive functional sub-types F_1, F_2, etc., taking those side effects in terms of different reaction norms into account (see also Bechtel and Mundale 1999 as regards the possibility to introduce more fine-grained functional concepts of the special sciences).

These sub-types are no longer multiply realizable, since any molecular difference that is relevant to distinguish between different types of realizers leads to specific functional differences – to a unique reaction norm, for instance. The functionally defined sub-types hence correspond to one type of molecular configuration each, bringing about the effects that define F in one particular way. These sub-types thus are nomologically coextensive with the physical or molecular types P_1, P_2, etc. By means of these sub-types we hence attain types or concepts of classical genetics that are nomologically coextensive with molecular types or concepts and thus make it possible to reduce classical genetics to a molecular theory in a functional manner.

More precisely and more generally speaking, (1) within an encompassing fundamental physical or molecular theory T_2, one builds the concepts P_1, P_2, etc. capturing the differences in composition among the physical configurations that are all described by the same concept F in T_1. (2) One makes F more precise by building functional sub-concepts (sub-types) F_1, F_2, etc. of F, seizing the systematic side effects linked to the different ways of producing the effects that define F. Provided that one such functionally defined sub-concept can be construed for each type of realizer of F in such a way that the former grasps the functional differences to which the latter give rise under certain circumstances, it follows that these sub-concepts F_1, F_2, etc. are nomologically coextensive with the concepts P_1, P_2, etc. (3) One can reduce any concept F of T_1 to T_2 via F_1, F_2, etc. and P_1, P_2, etc. Starting from T_2, one builds P_1, P_2, etc. and then deduces F_1, F_2, etc. from P_1, P_2, etc. given the nomological coextension. One gains then F by abstracting from the conceptualization of the functional side effects contained in F_1, F_2, etc, retaining only the main functional specification they have in common, which is nothing but the functional definition of F. This abstraction step depends on what the world is like rather than solely on our heuristic and practical aims. It enables thereby to highlight genuine causal similarities in the world that Kim's model and the new wave reductionism cannot account for. As regards the laws, one can formulate the laws of T_1 in terms of F_1, F_2, etc. by adding more functional details. Given the nomological coextension, one can deduce these sub-type laws from the laws of T_2, couched in terms of P_1, P_2, etc. and then gain the laws of T_1 formulated in terms of F by a theory-immanent abstraction from functional details (that are not relevant in many environmental contexts) (see Esfeld and Sachse 2011, chapters 4 and 5, for more details as regards the reduction of molecular biology and Soom, Sachse and Esfeld 2010 for an application of this strategy to folk psychology).

This account of reduction by means of functionally defined sub-concepts has two decisive virtues. In the first place, due to the fact that this approach proceeds by functionalization of the higher level concepts and property types, it yields reductive explanations of *why* certain entities making true the application of the concepts P_1, P_2, etc. also make true the application of the concepts F_1, F_2, etc., and thereby the application of the concept F. Moreover, the physical concepts P_1, P_2, etc. explain *how* certain entities in the worlds fulfil the causal roles defining the concepts F_1, F_2, etc. as well as F. This is how this account incorporates the explanatory virtues of functional reduction.

Secondly, the above-mentioned sub-concepts are not construed in a group-specific way based on physical criteria, but in terms of purely functional differences only. Taking the functional definition of F as a starting point, the functional sub-concepts F_1 and F_2 of F are distinct only by conceptualizing the different ways in which the effects that define F are produced. Consequently, F always has the same substantial "specification of the function" in F_1, F_2: these sub-concepts clearly express for biologists what their referents *functionally* have in common and what their *functional* differences are. Consequently, multiple realization turns out to be an *intra-theoretic* issue, since the relation between F_1, F_2 and F is a matter of variation of the degree of precision in the description of the causal role that characterizes F. Here, the variation of the degree of precision depends on what environmental conditions obtain. By contrast, in Lewis' and Kim's account, multiple realization remains an *inter-theoretic* issue, with respect to which, as argued, the introduction of group-specific concepts does not provide any help due to their hybrid – both physical and functional – individuation. This is why the present proposal does not put the scientific quality of the concept F – its suitability to seize a natural kind – and the laws couched in terms of F in jeopardy, but vindicates that scientific quality by systematically linking F and the laws in terms of F with molecular biology, and finally physics.

Let us point out an additional merit of this proposal that concerns the position occupied by the special sciences in a comprehensive system of scientific knowledge. On the basis of in the last resort the fundamental physical laws, one can formulate laws in terms of P_1, P_2, etc. that refer to the properties on which classical genetics focuses. From those laws, one can deduce genetical laws in terms of F_1, F_2, etc. given the nomological coextension of these concepts. One then reaches the laws and explanations in terms of F by neglecting the functional side effects originally taken into account by F_1, F_2, etc. in order to retrieve the concept F. Since the "specification of the function" of F is contained in each of its sub-concepts, there is no threat of elimination for the abstract concept F. The abstract laws of classical genetics couched in terms of F are non-molecular (non-physical) and not replaceable by molecular genetics in the sense that there is no single molecular law having the same extension as any of these laws. The molecular laws are too general and those molecular (physical) concepts that focus on the composition of the complex configurations in question (the concepts P_1, P_2, etc.) are too restricted. When talking about complex configurations such as e.g. genes, or whole organisms, the molecular concepts focus on their composition. Due to selection there are salient causal similarities among effects that such complex configurations produce as a whole although they differ in composition. The concepts seizing these similarities are therefore with good reason not considered as molecular concepts, but taken to be concepts of classical genetics. This is why, in addition to provide a conservative reduction by systematically linking F and the laws in terms of F with molecular biology, and finally physics, this account of functional reduction vindicates the scientific indispensability of classical genetics and the special sciences in general, since it is *only* by means of abstract functional concepts that we are able to bring out objective patterns of similarities that apply to relatively large sets of physically different entities under certain environmental circumstances. None of the current other accounts of inter-theoretic reduction can provide an equivalent outcome.

In conclusion, the merit of Nagelian reduction is to point out the only way open for a theory reduction, namely a deduction of the laws of the reduced theory T_1 from the laws of the reducing theory T_2 by means of biconditionals. The need for biconditionals is implicitly also acknowledged in Lewis' and Kim's account, seeking for group-specific biconditionals. In this paper, we have improved on Lewis' and Kim's account by replacing the group-specific types with functional sub-types or sub-concepts that are construed by relying only on the conceptual means of T_1 and that are coextensive with the realizer types described in the vocabulary of T_2.

Functional reduction provides, via the notion of physical realization, explanations of why there are in the world the properties on which the special sciences focus. However, multiple realization seems to rule out the reduction of the theories of the special sciences to physical theories. But the reductive, functional explanations of property tokens in the domain of a theory of the special sciences cannot stand on their own, as our discussion of Lewis' and Kim's account has made evident; for the scientific quality of the types in which the special sciences trade then gets lost. By contrast to what Kim (2008, pp. 108-112) claims, the concepts of the special sciences are not purely conventional, but seize salient similarities (natural kinds, homogeneous patterns) in nature, since selection abstracts in many environmental contexts from physical or molecular differences; but since there always are also environmental contexts possible in which these very physical or molecular differences are pertinent to selection, a conservative reduction of the types and concepts of the special sciences via purely functional sub-types or sub-concepts to physical or molecular types or concepts is possible. In thus showing how reductive, functional explanations can be expanded into a theory reduction via functional sub-types, we have married the merits of Nagelian reduction and functional reduction – achieving functional, reductive explanations that are backed up by a theory reduction that vindicates the scientific quality of the theories of the special sciences.

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