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Emergence and the Final Theory, or: How to Make Scientific Progress Sustainable[*]

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Abstract

Convergent scientific realism entails that science will sooner or later arrive at the final theory of the fundamental constituents of matter. At that stage, all fundamental truths about nature will be discovered so that the search for basic principle seems bound to come to a halt. I explore options for a non-convergent scientific realism that allows for sustained progress in basic research. I defend the views that the coherence of non-convergent realism requires an emergence claim and that this claim can be supported. I develop the example of the relation between equivalence classes among biological functions and their physiological realizations. Given strongly emergent laws in the sense elaborated in the paper, progress in basic research may survive the discovery of the laws governing the tinymost parts of matter.

Keywords: emergence, final theory, functional explanation, scientific realism.

Science is faced with an ever-changing variety of challenges. New issues arise constantly, and science is thought to provide the standard toolkit for their treatment. Science progresses at a quick pace; it fuels technological change and induces profound transformations in economy and society as a whole. The question I wish to address is whether this advance motion can last. Ongoing scientific progress presupposes that nature is structured in a

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suitable way. I wish to clarify what these conditions on the part of nature are like – or what it takes to make scientific progress sustainable.

1. Scientific Realism, the Exhaustion of Nature, and the Final Theory

What could possibly bring progress to a halt is the demands we place on it. We want substantial improvement, not mere change. And we want it with respect to the principles, not just some derivative elements. Without such constraints progress would be easy to get by piling up trivia. We could painstakingly register the facts as they occur, describing each facet in as detailed a fashion as humanly possible. Since exact replication is rare, we may trust that such a collection of truths would grow unabatedly. But this type of unlimited advance is less than thrilling. The ongoing accumulation of insipid reports is a cause of concern rather than delight. We want interesting novelty. I take it that scientific knowledge is distinguished, roughly speaking, by its unifying power and its reliability. Scientific theories are worthwhile in virtue of their conceptual and empirical achievements. Unification means that a few principles are sufficient for dealing with a large array of facts in a precise manner. Reliability presupposes that these principles are well-tested. In order to be acceptable, scientific theories are required to satisfy demanding criteria or pass severe tests of a kind which these theories can be expected to fail if they are wrong. This methodological lesson is equally part of the works of Imre Lakatos, Larry Laudan, and Deborah Mayo (Lakatos 1970, 31-47; Laudan 1990, 18-19; Mayo 1996, 7-11, 174-187). Scientific progress is constituted by the growth of knowledge thus distinguished.

A further issue is which empirical and conceptual virtues of theoretical claims, if any, justify the acceptance of such claims as representing reality. According to scientific realism, the principles of successful, or outstandingly successful, theories refer to truly existing objects, causal processes or natural kinds. Elsewhere I have argued for a brand of scientific realism which invokes a particular type of excellence, namely, strong success. A strongly successful theory is distinguished by the correct prediction of novel effects or the anticipation of novel relations among relevant phenomena. The basis of a realist interpretation of strongly successful theories is the so-called miracle argument. It states that achievements of this kind are to count as "miracles," i.e., as utterly mysterious and inexplicable, unless it is assumed that the theory in question has captured the pertinent features of reality truthfully. An inference to the best explanation justifies the assumption that there is some truth in such theories (Carrier 1991, 24-28; Carrier 1993, 403-404; Carrier 2003).

The credentials of this argument do not really matter. It suffices to take into account that there is a large number of devoted and practicing realists. In particular, the vast majority of scientists and philosophers of science subscribe to the view that at least some theories in the mature sciences are reliable enough to be trusted ontologically. Such theories are approximately true, and if a theory thus distinguished refers to certain entities, processes, or natural kinds these are rightly assumed to form part of the inventory of nature.

Scientific realism usually includes views about the progress of science. It is assumed that science manages to come closer to the truth about the natural world. This notion of convergent realism suggests that science increasingly exhausts nature in epistemic respect. If science is assumed to successfully approach reality, it should be done sooner or later. Science should reach a point at which all existing entities are uncovered and their properties and relations truthfully captured. Consequently, scientific realism faces the prospect that progress in fundamental research will come to an end. It entails the vision of a final theory for which there is nothing left to unveil. All fundamental matters will be settled. The particle physicist Steven Weinberg has famously advocated this conclusion. He observes a strikingly convergent pattern of "arrows of explanation." Generalizations are explained by more comprehensive theories and again by deeper principles. And wherever you start asking for the causes of physical, chemical, or biological phenomena, answers will eventually draw on particle interactions and thus rely on the standard model of particle physics (Weinberg 1992, 19, 32). History of science exhibits the same convergence. The historical succession of more comprehensive and more unified theories can be expected to approach the final theory where the level of maximum depth is reached and the search for fundamental principles completed (Weinberg 1992, 231-232, 235).

It deserves emphasis that arrival at this stage of completion does not necessarily mean the end of science, not even the end of basic science, that is, epistemically oriented and not primarily application-driven research. Rather, the prospect of a saturated science squares with Richard Feynman's "chess model" of progress. The rules of chess are completely known; nothing new will ever turn up at the fundamental level. And yet new chess games can be played unlimitedly. Likewise, if all the fundamental laws of nature were in, we could still go on to explore their consequences forever (Horgan 1996, 175-176; see Rescher 1978, 40-41). The chess model highlights the fact that the completion of fundamental science, which is targeting the tinymost constituents of matter, would leave large chunks of purely epistemically oriented science unaffected. Still, the chess model precludes the unlimited continuation of progress in fundamental matters. Given the final theory, the system of the world is complete.

This consideration brings out the tension between the realist claim that scientific theories reliably penetrate the inner workings of nature and the notion of ongoing scientific progress. Barring Blaise Pascal's vision of an endless series of worlds within worlds – distinguished by charm rather than credibility –, there is a distinguished, fundamental layer of entities or processes. Once this layer of reality is understood, basic science will be confined to tracing the consequences of this final theory. Nothing new will ever arise at this deepest epistemic level, and fundamental science will come to an end. It is at this juncture that the conflict between scientific realism and the notion of incessant progress breaks out. The issue I wish to address is whether sustained accumulation of fundamental or ultimate truths about the universe is possible. I want to elaborate how to give a coherent account of non-exhaustive, realistically construed progress in basic matters.

2. Changing Values for Resuscitating Stagnant Science

Laudan's reticulational model of scientific rationality places the agreement of aims, methodological rules, and scientific theories at the focus. Methodological rules state means-end relations; they specify procedures that are supposed to promote the aims of science in light of what the world is like. Such rules are justified on account of their appropriateness to reaching certain aims or goals, and Laudan claimed that goals of science have been subject to alteration over the past centuries. Galileo and Descartes aspired to a rational mechanics, guided by the ideal of intelligibility. Newton failed to fit gravitation into the mechanistic framework and switched over to the goal of empirically proven knowledge. Early in the 19th century unobservable entities such as electric charges or magnetic fields were included in the realm of science, and the understanding of these entities was accepted as a major goal of research (Laudan 1984, 42-66).

The reticulational model suggests a way out of the gloomy scenario of science in its barren end state: if a goal is reached, adopt another one! The allegedly final state could simply be taken as an indication of a lack of imagination as to what science can accomplish. So, here's the recipe for reanimation: change values. Abandon the old-fashioned aims of science and adopt fresh ones. This is by no means an abstract consideration. In fact, we are witnessing two endeavors that can be interpreted along these lines: the virtues of *emancipation* and *control* have gained prominence in some quarters and are intended to replace traditional criteria like unification or reliability. These approaches can be viewed as attempts to open up new horizons for science as a whole – with the no doubt unintended effect to make room for substantial progress regarding the principles.

Emancipation is among the prime commitments of social constructivists of all sorts. Scientific theories, the argument runs, are always underdetermined by available evidence. Experience fails to single out one theory as the correct one. There is room for choice which needs to be filled by appeal to non-empirical criteria. But if non-empirical considerations are to be drawn on anyway, we should bring to bear the right ones, which means, values we share. Political factors have frequently been claimed to influence the development of science. But social constructivists go one step further: scientists *should* take political values into consideration when accepting a theory. Theory choice *should* be guided, among other things, by the goal of promoting justice in society (see Koertge 2000, S49-S53).

Control is a second keyword, indicative of changing axiological commitments. Large areas of modern research are characterized by *application dominance*. That is, theoretical innovations do not respond to epistemically relevant challenges but are intended to promote economic goals and eventually to produce marketable goods. The aim is to control phenomena for the benefit of humankind – or a particular company. The interests and demands of future users shape the research agenda of a scientific discipline. Chemistry or parts of biology provide examples. Research is a matter of designing molecules for a given purpose or of blocking the spread of a disease.

It has been observed that application-dominated science develops a characteristic pattern of explanation. Comprehensive theories are rarely invoked; more common is a problem-specific approach. Context-dependent local models are predominant (Gibbons et al. 1994, 14, 23, 28-30, 43-44). Problems of practical importance, such as the appropriate array of fields in a fusion reactor or the mechanism of high-temperature superconductivity, are frequently treated using phenomenological models that are only loosely connected to quantum mechanics as the pertinent fundamental theory. Rather, such models are governed by assumptions specific to the issue at hand. As a result, a compartmentalized structure of disparate models is generated, models that lack a unifying bond. Similarly, application dominated science is said to aim at contextualized causal relations. On this understanding, all that needs to be done is, for example, to identify the gene that triggers certain physiological processes and can thus be employed to produce a desired effect. The causal chains or mechanisms that connect the trigger with the outcome are ignored. What matters is to identify the levers to be pulled; how they are connected with the results is considered a subtlety that can safely be neglected (Fox Keller 2000, 141-142).

Research projects of this sort are shaped by practical concerns and involve the renunciation of a genuinely epistemic commitment. We are faced with an engineering approach in which the proper functioning of certain devices is the sole criterion of adequacy for the underlying conception. Whether such a conception fits in with the wider nomological or causal framework is not considered important. If it works everything's fine.

The lesson to be drawn from these two examples is that changing values can backfire. Rather than breaking new ground for science, the ideal of knowledge is sacrificed for power, for the capacity to act politically or technologically. But an epistemic commitment is essential to science. In this vein, both alternative approaches to science reintroduce a gulf that was originally bridged by Francis Bacon, the gulf between knowledge and power, or between nature and art (i.e., technology). This is a high price to pay for resuscitating stagnant science. Changing values might amount to abandoning epistemic values of prime importance, such as reliability and unification. Accordingly, what at first appeared as a way of relieving an allegedly complete science of the burden of past achievements now seems more like a serious limitation. It could lead to renouncing the goals of knowledge and epistemic progress. Progress isn't saved, it's abolished. Science isn't that malleable, after all; it is bound to stick to epistemic commitments.

3. Complexity and the Final Theory

The assumption of a final theory is intertwined with a reductionist view of the structure of science. The axioms of this theory are supposed to account for the features of all relevant entities and processes at all higher levels of complexity.[1] Weinberg's vision of a final theory explicitly endorses a reductive relationship between the totality of physical entities and processes and the standard model of particle physics (Weinberg 1992, 51-58). Commitment to the finite character of basic research is assumed to involve the following

[1] The explanatory relationship is conceived in different ways by different authors. For instance, Nagel's standard model diverges from Kim's functionalist approach. See Nagel 1961, 336-366; Kim 1997.

contentions. There is a set of fundamental laws applying to the most elementary constituents of matter. This set accommodates the sum total of entities and processes in the world, and it cannot be traced back to further principles. This relation of accommodation is unanimously taken to include some sort of "in-principle explanation." The "in principle" proviso is supposed to take care of instances where we have reason to believe that the failure to fit them into the final theory is due to human, rather than factual, limitations.

These considerations show that the assumption of the existence of a final theory brings certain commitments in its train. In particular, these commitments restrict the range of admissible patterns of scientific progress. These patterns have to be compatible with the chess model (see sec. 1): The laws governing the fundamental entities and processes unambiguously determine everything that happens in the universe. But elaborating the bearing of these laws on the multifarious events and intricate processes found in nature may take endless pains.

The first thing to be noted is the import of the "in principle" clause added to the claim of comprehensive explainability. Human epistemic frailty is no justification for denying "in principle" explicability. Deterministic chaos, for instance, agrees well with the chess model and is compatible with the commitment to a final theory. The fundamental laws of chaotic systems are completely known; only their consequences are difficult to trace. Thus, mere complexity does not provide a sufficient reason for denying explanatory dependence. The same goes for the instrumentalist conception of biology as advocated by Alexander Rosenberg. It is because of human inability to keep track of all the molecules that collectively make up an organism, that biological features cannot be derived from the fundamental laws of physics (Rosenberg 1994, Chap. 1). But explicability is maintained "in principle": biological features are supposed to be determined by the behavior of microconstituents. Rosenberg's biological instrumentalism squares with the commitment to a final theory.

Another type of relationship between theories or explanations that agrees with reductionism and finitism is "weak emergence." This notion suggests a layered structure with different properties and processes at each level. The idea is that, while the relevant entities are governed by diverse laws, these laws can eventually be traced back to the same body of fundamental laws. If weak emergence obtains, it is still possible to account for the relevant properties and processes "in principle" by the laws governing elementary entities and their interactions. For instance, the bond between the oxygen atoms *within* an oxygen molecule is of covalent nature and produced by a quantum mechanical effect of electron sharing, while the bond *between* oxygen molecules is brought about by electric forces which arise from fluctuations in the electron densities of the atoms. Similarly, the atoms *within* a protein molecule are held together by covalent and ionic bonds, whereas the bond *between* protein molecules depends on their spatial shapes. In general, the processes *within* a system may be due to mechanisms or laws different from those that govern the interaction *between* such systems. Complexity demands recourse to different explanatory resources at various levels of organization.

However, nothing in this account is in conflict with reductionism. At the end of the day, all these diverse laws may well be reducible to the principles governing the behavior of micro-constituents. In fact, the various mechanisms of chemical bonding can all be explained by quantum theory (if glossing over some subtle difficulties is granted). Weak emergence entails nothing that could rule out such a reductive relationship. No in-principle gaps separate the higher-level features from the fundamental entities and processes. Weak emergence can be accommodated by the chess model.

Likewise, most of the arguments Nicholas Rescher advances in favor of perpetual progress leave the chess model unscathed. These arguments fail to rule out a notion of progress according to which an unchanged set of principles is unceasingly elaborated. Rescher draws support for unlimited progress from methodological features of science, which means, conversely, that the arguments are supposed to remain unaffected by assumptions about the structure of nature. The distinguishing feature of Rescher's approach is the attempt to establish the unboundedness claim by considering the way *science* proceeds; the way *nature* operates need not be taken into account. The endlessness of scientific progress does not require limitlessness on the side of the objects, which means that no infinitude of nature needs to be postulated. It is rather the structure of the information-acquiring processes that speaks in favor of incessant progress (Rescher 1999, 81). For reasons of succinctness I select for scrutiny the two most widely received arguments to this effect, namely, the argument from "erotetic propagation" and the argument from the interactive character of the growth of scientific knowledge.

First, Rescher's claim is that answering questions engenders new questions. It follows that scientific discoveries create new problems which in their turn keep scientific research afloat. The mechanism of erotetic propagation is supposed to work as follows. Posing a question commits one to certain presuppositions on which the legitimacy and propriety of this question rest. If the atomic weight of a given element is at issue, it is presupposed that there are atoms with certain weights. The answer to a question is integrated into the system of knowledge and hence constitutes a presupposition of further questions. That is, the answer changes factual assumptions underlying future research and thus makes new questions possible.

The alternative to answering a question is to dismiss it, that is, to reject it as being ill-posed. This happens if one of the presuppositions of the question is denied by the pertinent theory. For instance, in present-day science it is inappropriate to ask for the properties of phlogiston, caloric or the luminiferous ether. Disallowing questions requires removal of their presuppositions from the system of knowledge. And the reorientation going along with this process entails theoretical innovation and, hence, progress – or so the argument runs.

Finally, it is also possible that a question remains unanswered and thus contributes all the more to promoting progress. After all, such a question provides a constant stimulus for working out new theoretical approaches and thus advances scientific innovation.

In sum, the three possible ways of dealing with a question, namely, answering it, dismissing it and leaving it open, all induce theoretical change. The conclusion is that scientific theory is bound to rejuvenate itself continually. Scientific method belongs in every toolkit of anti-aging procedures (Rescher 1999, 5-18; see Ruetsche 2000, 65-66).

But even if this threefold argument is granted, it does not demolish the notion of a final theory. The abundance of new questions does not imply the overthrow of the fundamental axioms. Nothing in the argument entails that the answers given to these incessantly arising questions affect the principles of natural science, i.e., the assumed final theory. These answers may well refer to remote theoretical details and lack all general bearing. In order to rule out a final theory, it is not sufficient to establish ongoing theoretical change. What is needed is unceasing revolutionary change. But Rescher's argument fails to rule out the possibility that the questions and answers endlessly cropping up in science are fairly trivial, easily answered and bereft of all relevance to the foundations of science (Almeder 1992, 215).

Actually, this type of progress, which is allowed by Rescher's account, squares nicely with the chess model. After all, there is no natural end to the series of chess problems and their solutions. Pondering new chess problems certainly contributes to a deeper understanding of what the rules of chess imply. But the rules themselves remain fixed and final. Likewise, all the new questions and answers generated by Rescher's erotetic propagation mechanism may concern subtle ramifications of the final principles, without involving their overthrow.

The second one of Rescher's chief arguments for unending progress draws on human intervention in nature. This argument from interaction rightly stresses that science only rarely registers what happens in untamed nature. Science produces its evidential basis through active interference with phenomena of interest; science "twists the lion's tail," as Bacon reportedly remarked (Hacking 1983, 149, 246). Experimental science is technology-driven, and technological innovation should break new empirical ground. New data arise from the application of increasingly advanced instruments, and the challenge to accommodate these data is met by thinking up novel theoretical systems (Rescher 1978, 45-46, 52, 134-136; Rescher 1999, 81-82).

Again, this argument fails to establish that the evidence procured by novel instruments and experiments is of a kind different from the kinds already known. It remains possible that our increasingly sophisticated equipment merely serves to uncover more of the same. Think of the improvement of analytical tools in chemistry. As far as I can see, this sort of technological refinement has generated no substantial revision of fundamental chemical doctrines. Rescher's interactive approach to scientific progress is not sufficient for giving support to the idea of perpetual change in fundamental matters. His approach does not demonstrate that the principles of natural science continue to be overturned and replaced by principles of a different sort. This means that Rescher's approach is compatible with the chess model and, consequently, with the prospect of a final theory.

4. Emergence: Classical, Weak, and Strong

These considerations show that complexity *simpliciter* is insufficient for underwriting continual progress in fundamental matters. Complexity may produce mere difference among levels of organization without implying any kind of opposition between the pertinent explanatory resources. A motor car and a jet engine use different mechanisms of propagation, but both can be explained by the same set of mechanical and chemical principles. Only in-principle diversity could give progress in basic matters another chance.

Unlike weak emergence, the relation of *classical emergence*, as introduced by Charles D. Broad in 1925, is suitable for outlining a structure of explanatory layers which are separated by strict boundaries. Owing to some in-principle constraint, emergent properties of a composite system cannot be explained by the properties of its constituents and their interrelations. To be sure, the properties of the composite system are determined by those of its components; no additional factors intervene. Yet it is impossible to account for some of the qualities of the whole on the basis of the characteristics of the parts by relying on comprehensive laws. One of Broad's examples concerns the chemical transformation of hydrogen and oxygen into water. As water can be generated reliably from the elements, the latter are sufficient for bringing about the compound. Yet the chemistry of Broad's time did not contain the slightest clue to the way this drastic property change is produced. It appeared utterly mysterious how two gases could bring about a liquid. Thus, emergent properties differ qualitatively from the properties of their respective bases but are still lawfully related to them. However, this specific lawful relation cannot be explained by overarching theoretical principles (Broad 1925, 58-66).

The features of classical emergence are *effective determination* and *explanatory limitation*. As a matter of fact, base properties fix emergent features but the latter cannot adequately be accounted for by exclusively drawing on the former. The occurrence of qualitatively different properties in complex systems only justifies an emergence claim if these properties, first, cannot be traced back to properties of the parts along with their interactions, and, second, if this failure arises from an in-principle deficiency. Weak emergence involves a qualitative difference between relevant properties as well as effective determination. But this difference is amenable to treatment by overarching theoretical principles. By contrast, classical emergence involves nomological mavericks, cut off from the system of knowledge. The particular laws governing the production of classically emergent properties are considered "brute," "unique," and "ultimate." Broad approvingly quotes Samuel Alexander's recommendation to accept emergent properties with an attitude of "natural piety" (Broad 1925, 55); they can only be registered but not explained.

The notion of classical emergence suffers from a lack of persuasive examples. Its alleged instances have vanished since Broad's time. In particular, quantum chemistry has proved able to account for supposedly inexplicable property changes. This is no accident; the situation envisaged by Broad seems intrinsically unstable. Science essentially aims to integrate seemingly isolated relations into a nomological framework. Gradually a theory is built around an initially odd effect. Let's adapt Broad's scenario so as to take scientific striving for unification into consideration. Assume we end up with a number of disparate theories which apply to different properties of the same objects: none of these theories is reducible to another one, nor can they be integrated into one coherent network (other than by trivial conjunction). I call this type of relation "strong emergence."

5. Strong Emergence: New Vistas of Progress in Basic Matters

Strong emergence breaks the confines of the chess model of progress. Assume we are faced with a complete final theory which comprehensively accounts for the behavior of the fundamental parts of matter. This theory fails to comprise the emergent features of composite systems which are characterized by their inexplainability by the laws pertaining to their respective constituents. As a matter of definition, strongly emergent properties are beyond the scope of a final theory in this sense. I call a law *ultimate* if it cannot be traced back to deeper principles; an ultimate law is not derivable from any deeper truth. The chess model entails that the fundamental laws, referring to the most elementary entities and their interactions, coincide with the ultimate laws. By contrast, strong emergentism implies that there are ultimate laws of composite systems, that is, ultimate but non-fundamental laws. Such emergent laws are not obtained by applying the final theory to these systems. Basic research does not adopt a chess-like structure since the final theory fails to provide all the rules of the game.

In this framework, distinctly holistic properties and laws are assumed for complex objects, even though such objects are taken to be “nothing but” aggregates of their parts. These higher-level features are not derivative but ultimate themselves – in spite of applying to composite and structured aggregates. Complex objects provide a field of basic research even after the most minute particles are detected and their interactions recorded. Within the emergentist framework, and in contrast to the chess model, complexity ensures the ongoing character of basic scientific progress even after the advent of a complete fundamental theory (Carrier 2000b, 100-101). The question is, however: can strong emergence avoid the emptiness that invalidated classical emergence? Conversely speaking: on which feature could an in-principle nonreducibility claim be based? This is my suggestion: reciprocal heterogeneous multiplicity.

6. Benefits of Mutual Assistance or, the Reciprocal Unification of Biological Functions and their Physiological Realizations

Multiple realization is one of the salient features of biological and mental phenomena. Take biological functions and physiological realizations as examples. For instance, the function of establishing communication among cells or within cells is performed by so-called signal molecules. These messenger molecules are chemically distinct or even heterogeneous; they may be proteins, amino acids, fatty acid derivatives, and many more (Kincaid 1990, 584). The heterogeneity of this class of realizations means that there is no chemical criterion for singling out the relevant entities. The uniform function of biological signaling is realized by divergent chemical processes which cannot be identified on the sole basis of their chemical properties (Carrier 2000a, 182-183).

Multiple realization was taken to block reducibility, but its bearing has diminished under the force of recent criticism. It is argued that even in cases of multiple realization the properties of interest (functions or higher-level features in general) are unambiguously fixed by properties of the parts and their interactions. Furthermore, explaining higher-level features in terms of the interactions of the pertinent fundamental entities provides us with the comprehensive picture. Nothing is left unexplained. It is true, such a micro-explanation may contain superfluous details. When signaling is at issue, the molecular particulars may be irrelevant. But saying more than was asked for doesn't invalidate the explanation. The fundamental story is the true story, and all higher-level accounts arise from human cognitive constraints and do not exhibit any objective superiority (Rosenberg 1994, Chap. 2; Sober 1999, 546-549).

Whatever the import of this criticism may be, multiple realization is not the only obstacle to reduction. The converse aspect is important as well: a given entity may perform a variety of functions. One of the reasons for this variety is the intrusion of additional factors. Whether or not a signal molecule does its duty depends on the presence of suitable receptors and a host of other conditions. The function of an object or process is context-dependent in that it may be altered or vitiated by external circumstances (Kincaid 1990, 579, 581-582). However, there is another, further-reaching variability of function. One and the same object or process may fulfill varied, or even heterogeneous, functions under identical conditions.

My claim is that there is a multiplicity of heterogeneous realizations of the same functions and at the same time a multiplicity of heterogeneous functions of the same objects or processes. The origin of breathing is a case in point. According to one of the evolutionary accounts presently on offer, the development of breathing was initiated by the spread of green plants. Owing to the increasing intensity of photosynthesis, the atmospheric oxygen content grew. But oxygen is chemically aggressive and tends to destroy organic molecules that are critical to the survival of organisms. Evolution thus developed a means of neutralizing the toxic impact of oxygen atoms (or "free radicals"):

oxygen compounds were formed that are chemically more inert and do less or no damage to an organism. As a result, energy was gained as a side-effect of detoxification, and breathing became a chief source of metabolic energy supply.

Consequently, the process of oxide formation in organisms serves two different ends. The two functions of detoxification and energy supply are fulfilled at the same time under the same circumstances. Moreover, these ends are clearly heterogeneous; there is no functional criterion that could establish an equivalence relation between them while leaving out other functions which are not connected with oxide formation (such as hormone level control or biological clock). Conversely, each of these two functions can be performed using different mechanisms. Energy can also be supplied by anaerobic decomposition of carbohydrates or by photosynthesis. And the dangerous effects of oxygen could also be blocked by compounds formed through endothermic reactions. This shows that the various chemical realizations of the same function may not only be different but heterogeneous. Drawing on chemical criteria alone while ignoring the functional aspects of energy gain, it is impossible to identify the relevant set of processes, namely, breathing, anaerobic decomposition, and photosynthesis (and at the same time leaving out other reactions that are similar in chemical respects). Similarly, it is impossible to distinguish harmless from potentially damaging oxides on exclusively chemical grounds. What is needed, in addition, is an appeal to functional features such as toxicity.

This shows that one and the same object or mechanism may perform a variety of functions under the same environmental conditions. Functional diversity is not always due to an intrusion of additional influences. Oxide formation serves two heterogeneous functions simultaneously. Conversely, each of the functions could be realized by various heterogeneous mechanisms. In sum, we are faced with reciprocal heterogeneous multiplicity.

This is a wide-spread characteristic that extends to a large number of biological processes. Originally, wings were presumably selected as thermoregulatory devices, that is, as a means of cooling the relevant organism. And they operated as aerodynamic devices afterward; they improved the capacity to fly. The human brain constitutes another example. On the one hand, it clearly serves a multitude of different, or even heterogeneous, purposes, reaching from spatial orientation to melody recognition. On the other hand, higher cognitive faculties may alternatively be realized by a von-Neumann scheme of the kind underlying common digital computers or by neural networks. There are marked contrasts between the relevant mechanisms and implementations. All in all, the physiological processes in the brain serve a multitude of functions, and each of these functions may be realized differently.

Reciprocal heterogeneous multiplicity between functions and their realizations entails the following peculiarity: Unifying a set of functions may require recourse to the realizations of these functions, and unifying a set of physical entities may demand appeal to the functions these entities fulfill. Given that a function is realized by heterogeneous mechanisms, similarity among the mechanisms is exclusively grounded on their functional equivalence. Given that an entity performs heterogeneous functions, similarity among the functions exclusively rests on sameness of realization. What is equal in functional respects may be disparate physically; and what is of the same kind physically may be diverse functionally. The equivalence classes of functions and their realizations cross-classify each other.[2]

The emergent property arising from this feature is *sameness in kind*. Functional concepts serve to unify physical entities that remain heterogeneous at the physical level. Conversely, physical concepts contribute to unifying functions that are heterogeneous at the functional level. Functional concepts like “detoxification” and “energy supply” lump together physically distinct instances and make overarching explanations possible. On the level of relevant mechanisms, such uniform explanations crumble into physically disparate pieces. Without a functional bond, breathing, anaerobic processes, and photosynthesis constitute quite distinct chemical processes. Conversely, the different functions of one and the same mechanism make it clear that recourse to the realizations allows a particular type of unified explanation as well. Restriction to functions would fail to grasp that it is the same physical object or process that is responsible for a whole class of functionally disparate effects. One needs the physical level to understand that the function of detoxification is realized by the same mechanism as the function of energy supply.

This mutual explanatory dependence does not extend to particular instances of functions and their realizations. There is no general difficulty to understand that and how a given mechanism performs a specific function. Similarly, the ascription of functions may rest on the discovery of relevant

[2] The general picture sketched here resembles the one emerging from Dupré (1993): a plurality of taxonomies that involve a number of cross-classifications. However, I focus on the relationship between functions and their realizations which Dupré touches on only briefly (1993, 125-127), and I give a different reason for the occurrence of cross-classifications, namely reciprocal multiple heterogeneity.

mechanisms. For example, identifying the recognition of shape, color and motion as the three distinctive features of perception is motivated by the fact that these three functions are realized by physiologically different mechanisms. Regarding particular cases, the connection between functions and realizations may be fairly direct, close, and unproblematic.

But the argument is not concerned with particular cases but with classes of entities and processes of the same kind. The issue is unification, and the claim is, first, that functional concepts are needed for unifying physically heterogeneous processes and, second, that physical concepts are required for giving a coherent account of functionally heterogeneous achievements. Note the symmetry of the conceptual situation. There is explanatory gain in either direction. Some explanations of similarity or sameness in kind can only be given by drawing on conceptual means supplied from outside. Sometimes unification demands outsourcing. But this entails that some explanations cannot be traced back to particle physics. Some accounts of similarity among physical entities need appeal to higher-level functional concepts. Biology and psychology, as disciplines that make extensive use of functions, tend to remain uncovered by the grand unification of particle physics.

7. Naturalized Functions and the Renewal of Epistemic Resources

The point of the argument is that appeals to functions as well as to physical mechanisms accomplish explanations that transcend the resources of the other level. This means that functional and physical theories cannot be reduced to one another since each accomplishes specific explanatory gains that cannot be matched by exclusive appeal to the conceptual resources of the other. Moreover, functional and physical approaches are distinct: the former disregard mechanisms and the latter are too fine-grained to capture the overarching functional level. Functional and physical accounts do not form a coherent whole; they can only be unified by trivial conjunction. As regards explanation of sameness in kind, we are faced with a case of strong emergence.

Adding a separate layer of functions to the fundamental level of microparticles and their interactions opens up new vistas for progress. Some phenomena escape the explanatory grip of the final theory. But this new spectrum of discoveries makes room for progress in the realistic sense of uncovering nature only on the condition that functions are part of the inventory of nature. If functions are to underwrite the prospects of a continued unveiling of nature's contrivances, functions need to be naturalized. Otherwise, one could conceive of functions as mere instrumentalist devices or regulative principles: functions do not exist in reality; they are nothing but conceptual inventions for a better understanding of the phenomena (Ratcliffe 2000, 118-119). In addition, such a naturalistic conception has to leave room for ascribing more than one function to a given entity or process. Only on that condition would the claimed multiplicity of functions and mechanisms be an objective feature of nature. In fact, the two mainstream approaches to functions are equally naturalistic and permit reciprocal multiplicity. On both approaches, functional explanations have realist import.

According to the etiological theory, the function of an object is the reason for its existence. The function of a biological structure is the effect which it was selected for and which explains why it is there (Wright 1973; see McLaughlin 2001, Chap. 5). A narrow etiological theory acknowledges only a single function: the reason for the genesis of a particular structure. A more ecumenical version takes functions as the effects that are responsible for the "origin or maintenance" of a structure[3]. This clause allows the inclusion of those effects among the functions of a biological structure that grant a selective advantage at present, and not merely during its formation.

Assume that detoxification was the effect which oxide formation was originally selected for so that energy supply is a side-effect. Suppose further that organisms developed more intricate and efficient procedures for getting rid of potentially damaging free oxygen (this is actually the case). If only detoxification had been at stake, breathing would have been discarded as a superfluous and costly procedure. This means that the biological reason for its sustained existence is a former side-effect, namely, energy supply. A more comprehensive reading of the etiological theory suggests that both effects qualify as naturalized functions.

The second chief approach to functions draws on the "causal role" of processes. More specifically, the operation of a system is represented as a sequence or interaction of a number of subsystems each of which is characterized by the task it performs. A suitable property of a system is explained in terms of the capacities of its components. To ascribe a function to an entity or process means to impute a capacity to it which contributes to generating a characteristic of the wider system that encompasses the entity or

[3] Allen & Bekoff characterize etiological functions by the clause that they are intendend to account for the "existence or maintenance" of biological traits (1995, 612). The explanation of the presence or maintenance of an entity or property also lies at the center of classic accounts of functions; Nagel 1961, 402-405; see Cummins 1975, 741, 745-747.

process in question. The function of the kidney is represented by its capacity to remove metabolic waste from blood because the performance of this task contributes to the survival or continued activity of the relevant organism. The capacities invoked by a substantial causal-role analysis are required to be less sophisticated than and different in type from the feature analyzed and exhibit a complex organization (Cummins 1975, 759-765; see McLaughlin 2001, Chap. 6).

Carl Craver rightly emphasized that causal-role functions can only be attributed to organized systems which are characterized by a complex arrangement of their component capacities. In such systems the components and their activities cannot be interchanged arbitrarily without disturbing the performance of the embedding system. The causal role of a component qualifies as a function only on the condition that this role cannot be intersubstituted with that of another component picked at random while maintaining the operation of the whole. If you replace a kidney with a heart, the removal of metabolic waste will suffer. Any such replacement has to meet strict demands if the activity of the organism is to remain unaffected (Craver 2001, 59).

This condition states that functions are only fulfilled by parts of organized wholes. Accordingly, it is ruled out to regard it as a function of a drop of water to enlarge the volume of the oceans. A causal role of that sort remains unchanged by arbitrary intersubstitutions: any randomly chosen drop could make the same causal contribution.

But more than organization is required to make causal-role functions an objective feature. On the face of it, every property of an organized system can be understood as resulting from interactions between component capacities and can consequently be subjected to a functional explanation. For example, the suitability of the human nose for supporting glasses could be taken as one of its functions, because this causal role undoubtedly contributes to improving many people's performance. It seems that there are no natural limits to the ascription of causal-role functions. Each property can apparently be accounted for functionalistically by conjuring up suitable capacities. The identification of causal-role functions seems to rest on judgments about what properties are significant. This relativization of function ascriptions appears to thwart the naturalization of causal-role functions (Craver 2001, 71).

Ascertaining the objectivity of functional explanations requires restricting the properties that can possibly be accounted for by attributing causal roles. The most plausible option is to proceed as in the etiological approach and to limit function ascriptions to properties that can be attributed to biological evolution. That is, such ascriptions are limited to properties related to biological fitness in Darwin's original sense: only those features can be analyzed by imputing causal roles that improves the prospect of survival or reproduction of the corresponding organism (Weber 2003, sec. 2.5). The appeal to biological evolution supports the claim that the pursuit of these goals is the result of the causal process of natural selection. Survival and reproduction are goals internal to an organism and can be naturalized by referring to biological processes. Moreover, survival and reproduction constitute two distinct goals and thus make it possible to ascribe more than one functional contribution to a given entity.

Construed in this way, the causal-role approach, no less than the etiological theory, yields the two features of functions I need: multiplicity and objectivity. Biological processes like oxide formation may contribute in more than one respect to the appropriate operation of an organism. And they may do so objectively. Assigning a function to a process involves the factual claims that this process actually produces the relevant effect and that this effect increases the fitness of the corresponding organism. It is a fact that oxygen compound formation contributes to neutralizing free radicals and serves as an energy source. Both capacities exist and they are relevant to the survival and reproduction of organisms. Thus, both can legitimately be employed in a functional analysis.

Consequently, the etiological theory and the causal-role account equally accept functions as part of nature and allow for a multiplicity of functions of the same entity or process. Functions are naturalized within each approach, and they come out as real and multiple. In virtue of their realist import, functions can underwrite strong emergence. That is, the strongly emergent relations between functions and their realizations are part of nature's modes of operation. It follows that strong emergence does not suffer from the emptiness that rendered classical emergence insignificant.

8. Strong Emergence and the Prospect of a Final Theory

Strong emergence transcends the boundaries of the chess model of progress. Emergent laws are ultimate, but not fundamental. They are ultimate in that they cannot be based on deeper principles, and they fail to be fundamental in that they do not apply to the final constituents of matter. Rather, such ultimate laws refer to composite objects and are essentially holistic in this sense. Emergent laws make room for discoveries and theories which are not covered by the most complete account of the elementary entities and their interactions. Although strong emergence conflicts with the chess model in that these emergent laws are irreducible in principle to the laws governing the fundamental constituents of matter, it does not strictly rule out the formulation of a final theory. The immediate conclusion to be drawn from strong emergence only concerns the structure of the final theory. Namely, this theory has to contain principles that irreducibly refer to composite objects. There is no way to account for all there is by exclusively relying on a micro-theory such as the standard model of particle physics. In contrast to Weinberg's contention (1992, 55), *not* all arrows of explanation converge on the standard model (see sec. 1, 6).

But this minimalist conclusion can be expanded in a cautious way. It is true, I argued for strong emergence only with respect to the equivalence classes among functions and their realizations. But I take this one type of examples to suggest that there are other properties of composite objects that exhibit a similarly intricate relationship to the properties of the fundamental constituents of matter. It is likely that there are more layers of reality, each governed in part by laws irreducible to those of completed particle physics.

In case this somewhat speculative conjecture is borne out, reality exhibits the structure of a "Borgesian library." This metaphor was articulated by Ian Hacking. It suggests that there is no single Book of Nature, but a library, each book of which is as brief as possible, yet each book of which is inconsistent with every other. No book is redundant. For every book, there is some humanly accessible bit of Nature such that that book, and no other, makes possible the comprehension, prediction and influencing of what is going on. (Hacking 1983, 219)

The picture is that reality is like a patchwork. Each of the patches can be described by an account that is unobjectionable in empirical as well as methodological respects. But the accounts of different patches do not mesh; they do not grow into a uniform fabric.

The notion of strong emergence and the examples presented in its favor serve to flesh out this general scheme, but at the same time they amend it. In contrast to Hacking's Borgesian vision, the theoretical layers separated by strong emergence are not inconsistent; they are unrelated. A strongly emergent theory of composite objects does not contradict a possible final theory of fundamental entities. Rather, both theories fail to account for the entire domain of relevant properties.

Strong emergence lends plausibility to Hacking's Borgesian picture. It makes one realize how a layered structure of theories, whose strate are separated by irremovable gaps of irreducibility, could come about in the first place. Once this notion is established, it is only a short step to surmise that a large number of additional such layers could exist, likewise separated from the fundamental one and yet essential for a comprehensive understanding of nature.

Strong emergence is the key to bringing the notion of ongoing progress in basic science into harmony with scientific realism. The initial worry was that should science improve its performance unceasingly, it is apparently bound to reach an end-state in which all truths are in (see sec. 1). Emergence offers a prospect such that new basic issues may arise and science progress without exhausting nature. As science proceeds, new sets of ultimate properties and laws concerning different layers of organization are brought within our horizons and offer pristine ground for theoretical work. I granted before that the mere existence of strong emergence fails to underwrite the notion of unending progress. Commitment to a multiplicity of such properties or laws is needed. But, first, if strong emergence is admitted in one case, other examples are likely to come up, and, second, it becomes clear that, conceptually speaking, the minimum investment necessary to make scientific realism compatible with the unboundedness of scientific progress in basic matters is the assumption of strongly emergent laws. That is, non-exhaustive realism can be made coherent by assuming strong emergence.

This consideration shows that Rescher's attempt to base the unboundedness of progress on features of science rather than nature goes awry. Strong emergence is a contingent matter whose appearance is in no way guaranteed by the particulars of "information-acquiring processes" (see sec. 3). The chess model of scientific progress is not invalidated by the structure of science or the mere complexity of nature. This takes a special level of complexity; what is required is strong emergence.

Rescher's combinatorial analogy concerning endless scientific progress tacitly presupposes strong emergence and thus assumes a contribution on the part of nature.

The example of written text in fact provides a helpful analogy for the sort of complexity in cognitive stratification that can underwrite the prospect of unending scientific discovery. Knowing the frequencies of the letters *a* and *t* in a certain group of texts yields virtually nothing as to the frequency of the word *at*. The laws of a given level of discovery need not anticipate or determine those of another. (Rescher 1999, 82)

This example turns on the consideration of two largely independent sets of properties, namely, syntactic and semantic properties. Mere combinatorial complexity does not suffice. Lots of algorithms can be conceived that produce strings of letters such that the probability that an *a* is followed by a *t* can be estimated accurately. This anticipation is thwarted because meaning is used as a means for ordering letters, and this property is inaccessible at the syntactic level of combining letters. I argued elsewhere that semantic equivalence (i.e., sameness of meaning) and physical equivalence (i.e., referential identity) exhibit the same peculiarity of reciprocal heterogeneous multiplicity and thus constitute another example of strong emergence (Carrier 2000c, 545-546). Rescher's combinatorial analogy is sound; but it rests on the tacit premise of strong emergence.

The moral can be applied to the relationship between reality and scientific change. The ideas that reality is stratified and that basic research in science can go on perpetually rest on the contingent assumption that strong emergence occurs. Science can only progress endlessly if nature lends a helping hand.[4]

9. Conclusion

Strong emergence provides a key to bringing scientific realism into harmony with the assumption that basic scientific progress goes on indefinitely. By searching for emergent laws, basic progress may survive the exhaustion of fundamental laws. My claim is that there is a promising candidate for strong emergence, namely, the property of "being of the same kind" with respect to relations between functions and their realizations. Recourse to functions may establish equivalence classes among physical entities that cannot be identified by relying on physical criteria alone. Recourse to mechanisms may introduce equivalence classes among functions that cannot be captured by using functional criteria. Neither level can be abandoned in favor of the other. The symmetry of the situation contrasts with the unidirectional dependence that is required for a reductive relationship. We are faced with theoretical clusters that remain separate for reasons of principle. The principle is that a relation of reciprocal multiplicity obtains between some of the

[4] This result is in harmony with Almeder's conclusion to the effect that there is no general epistemological justification for the assumption that the inventory of non-trivial questions to be addressed by science is infinite (Almeder 1992, Chap. 5). But Almeder goes on to claim that science would actually answer every question were it to continue indefinitely (ibid. 218). Given the option of a series of strongly emergent laws, as elaborated in this paper, I take it to be more plausible to expect that the number of new questions cropping up in the course of extending the rule of science to ever more sections of reality will be unlimited.

relevant equivalence classes – and this is constitutive of strong emergence. The type of emergentism sketched here is minimalist in that it only refers to kinds of similarity, not to individual events (as Broad's classical emergentism has it).

Multiple realization *simpliciter* and reciprocal heterogeneous multiplicity are different in at least one crucial respect. The impact of multiple realization may be constrained by arguments of the sort rehearsed earlier: there is only one true story, namely, the micro-story (see sec. 6). The more unifying account is introduced only because of the epistemic weakness of humans. We are at a loss to make sense of all the molecular details. Reciprocal multiplicity is distinct in that each of the two approaches, i.e., the functional and the physical one, is more detailed in one respect and more unifying in another. The situation is symmetrical. This blocks the easy way of choosing one of the approaches as fundamental and the other as derivative. Rather than a unidirectional relationship of premise and consequence, we encounter a sort of complementarity in Niels Bohr's sense. Bohr's notion combines inconsistency and unavoidability. The two approaches at issue involve incompatible equivalence classes which are jointly requisite for an exhaustive elucidation of the phenomena.

This suggests a picture of a stratified reality without one distinguished set of laws capable of capturing the totality of phenomena. Progress will be endless if science succeeds in uncovering ultimate laws at every layer. Strongly emergent properties are governed by such ultimate laws, and they can be shown to exist. I conclude that the odds aren't that bad for incessant basic progress of science.

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