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Inter-level relations in computer science, biology, and psychology*

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ABSTRACT *Investigations into inter-level relations in computer science, biology and psychology call for an* empirical *turn in the philosophy of mind. Rather than concentrate on* a priori *discussions of inter-level relations between "completed" sciences, a case is made for the actual study of the way inter-level relations grow out of the developing sciences. Thus, philosophical inquiries will be made more relevant to the sciences, and, more importantly, philosophical accounts of inter-level relations will be testable by confronting them with what really happens in science. Hence, close observation of the ever-changing reduction relations in the developing sciences, and revision of philosophical positions based on these empirical observations, may, in the long run, be more conducive to an adequate understanding of inter-level relations than a traditional* a priori *approach.*

1. Introduction

What is the gist of the arguments put forward in the previous three articles? Before we are in a position to draw some general conclusions from our discussions of

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inter-level reductions in the sciences, we want to briefly set the stage. It is true that most of the philosophers of science or of mind cited in our discussions have put forward their arguments and propounded their concepts with an eye to an ideal, finished science. For instance, Nagel's (1961) classical ideas on theory reduction can only be applied in the (rare) cases where both the higher-level theory and the lower-level theory are more or less completed, that is, formalized and axiomatized. Hence, for Nagel, theory reduction consists in deducing all sentences of the higher-level theory from the axioms and theorems of the lower-level theory. Obviously, this goal necessitates definitions of all higher-level concepts in terms of lower-level concepts. Thus, Nagel's ideas on reduction are a direct consequence of the traditional ideal of knowledge that usually is associated with Cartesianism, but which, as Beth (1959) has shown, could also be aptly called the Aristotelian ideal of knowledge. A key characteristic of these traditional ways of thinking about science is that they are *a priori* and *static*. Toulmin (1990) contrasts this traditional, rationalistic ideal of knowledge with the sceptical, empirical, fragmentary and historical view of knowledge as defended by, among others, Montaigne.

In the 1960s, due to his explorations in the history of science, Kuhn felt increasingly uncomfortable with the prevailing foundationalist attitude in the philosophy of science. His *The structure of scientific revolutions* (1962) reconstructs the philosophy of science, paying close attention to the historical development of science. For our present purposes, it is sufficient to note that Kuhn gave a new impetus to a *dynamic* philosophy of science: instead of concentrating on *a priori* conditions of ideal static knowledge, Kuhn furthers the systematic and empirical study of changes in scientific theories. Nevertheless, philosophical investigations aimed at specifying and defending *a priori* theories for ideal and static phenomena still dominate the agenda for much contemporary philosophy, ranging from ethics to the philosophy of mind.

Recent discussions in the philosophy of mind on reductionism and eliminativism try to find convincing arguments concerning the place and the status of the mental in a finished, purely physicalistic theory of the mind. In this way, these philosophers tried to develop a blueprint of, among other things, how inter-level reductions in the sciences should ideally be conducted, if such a reduction is possible in the first place. Such philosophical arguments do have some immediate practical significance: they provide some philosophical justification for preferring one research strategy in cognitive science to the detriment of another. Nevertheless, they can never provide decisive arguments for such a choice. It should be clear from our articles that we did not take arms against philosophical deliberations aimed at some indefinite point in the future. We do want, however, to assess the merits of these philosophical theories and concepts in describing scientific practice in real laboratory life (including the computer lab). We will try to assess the diagnostic value of concepts that are common currency in the philosophy of mind and science, such as "supervenience," "emergence," and "multiple realization," in illuminating real empirical work.

2. Inter-level reductions in computer science

Prima facie, the situation in computer science seems most in line with Nagel's classic ideas concerning theory reduction. In computer science a higher-level description language has an autonomous semantics, which enables users to interpret the higher-level language without prior knowledge of the semantics of lower-level languages. If desired, a process description in a higher-level language can be automated by translating this higher-level language (usually via a number of intermediate steps, via assemblers or compilers) into a lower-level language that directly relates to physical processes within a computer. Thus, "bridge laws" connecting higher-level and lower-level descriptions can be established. The required reduction relations that are formulated as a basis for these translations need to comply with the autonomous semantics of the higher-level description language that is translated and the semantics of the lower-level language into which it is translated. This constraint enables us to check whether a proposed formulation of a reduction relation is correct: a reduction relation is (to be) a meaning-preserving relation between expressions of a higher-level language L_2 and expressions of a lower-level language L_1. Verification of a reduction relation can be twofold. First, via *empirical verification* it can be checked whether the proposed reduction relation preserves the informal semantics of the reduced and the reducing language, which both have an informal autonomous semantics due to the fact that they were introduced to describe real-world processes. Second, via *computer-aided verification* it can be checked automatically whether the reduction relation preserves the formal semantics of the languages under consideration, as description languages usually are formalized languages.

Jonker *et al.* (2002) noticed that different translations of a higher-level language description φ may give rise to *different* lower-level language descriptions ψ and χ, all describing the same process in the real world. Hence, higher-level language descriptions are *multiple realizable* on lower-level language descriptions. The notion of "multiple realizability" is only a characteristic of a domain, to be used for analysis; the aim of using this concept is not to identify or synthesize the relationships between higher-level and lower-level description languages. In contrast, use of the notion of "supervenience" aims at expressing something more substantial about the relationships. However, this very abstract concept leaves us in the dark about the exact relations between higher-level and lower-level languages as well. Therefore, these conceptual instruments that have been developed in the philosophy of mind to analyse inter-level relations lack the required precision: they are axes rather than lancets. The notion of "context-specific reduction relation" is more specific. Though in some cases it may be unclear whether the notion can be applied, in cases where it *is* applicable, the notion provides a means to formulate precise relationships between higher-level expressions and lower-level expressions. Indeed, this conceptual instrument seems to provide an adequate means to describe and classify the variety of modelling and programming environments and platforms in computer science.

The paper by Jonker *et al.* (2002) subsequently focused, with an eye to some hotly debated issues in contemporary philosophy of mind, on *interpretation* and *use* of reduction relations in computer science: given reduction relations between a higher-level and a lower-level language, what are we going to do with them? Should we stop speaking of the objects of the reduced higher-level description language and applaud the "ontological simplification" the reductions provide us with? First, the authors note that it might well be that for human users, only the descriptions in higher-level languages are practicable, as descriptions in lower-level languages are too complex to be understood by humans. Dennett's (1987) tenets about the intentional stance's tractability advantages coincide quite neatly with the findings of Jonker *et al.* More importantly, inter-level reductions actually reinforce our belief in the reliability of the higher-level description languages.

We would, however, be too rash, if we extrapolated the paper's findings about inter-level reduction in computer science to issues in the philosophy of mind *tout court*, since the exact analogy between description languages in computer science and psychological explanations of behaviour is yet to be investigated more thoroughly. Jonker *et al.* showed that proposals for suitable formulations of reduction relations are evaluated on the basis of empirical criteria related to the semantics of the languages. Nevertheless, this feature of inter-level relations in computer science by itself is not a satisfactory answer to the following question: are higher-level languages describing processes in the physical or in the societal world of the same kind of abstract objects as psychological theories aiming to explain cognitive processes and behavioural patterns? Within computer science, the initial motivation for the construction of the higher-level description language was the need for a strictly regimented language to describe processes in real life, since such a regimented language would, if implemented, enable automation of these processes. Hence, higher-level description languages do describe patterns of phenomena in the real world, with which the dynamic patterns generated by implemented description languages (ought to) match.

Many authors writing on the philosophy of mind, such as Churchland (1984, pp. 71–72), prefer to interpret "folk psychology" as a (proto)scientific theory aiming to explain behaviour. Some authors, like Dennett (1991) and Jackson and Pettit (1990), have exploited concepts from computer science to discuss these matters. For example, Jackson and Pettit (1990) used the computer science notion of a "program" to develop an account of explanation tailored to the needs of biology, cognitive science and the social sciences. So, despite apparent dissimilarities between description languages in computer science and psychological explanations of behaviour, it might be the case that the similarities justify the extrapolation of the present philosophical findings about computer science to the philosophy of mind. Further research to clarify the matter in more detail would be helpful. One of the issues addressed in such further research might be the notion of intentionality: we may ask whether higher-level description languages contain *intentional* concepts. Do they *represent* something? Are they "*about*" states of affairs? If so, the situation in computer science would be even more relevant to the debate on reductionism in the philosophy of mind, since we would have a case on hand of a reduction of a language containing intentional concepts to a purely extensional language describing physical processes. Of course, it will just beg the question to assert that higher-level description languages in computer science lack intentional concepts, on the basis of the following *a priori* argument:

(1) In computer science, higher-level languages can be reduced to nonintentional lower-level languages;
(2) philosophers have shown that a reduction of intentional higher-level languages to nonintentional lower-level languages is impossible.

Therefore,

(3) philosophers have shown that higher-level languages in computer science are not intentional.

Hence, a detailed philosophical investigation of criteria for intentionality and the aforementioned autonomous semantics of higher-level languages must be conducted to throw more light on this matter of central importance in philosophical psychology.

3. *Integrating lower-level theories in cell biology*

The central goal in cell biology is to gain a complete understanding of what is going on in a living cell. Unlike the debates on reductionism in computer science and in biological psychology, in biology the reductionist problem is *not* the familiar one of finding inter-level relations between pre-existent higher-level theories and pre-existent lower-level theories, but rather the problem of integrating lower-level theories, data and theories from genetics, biochemistry, physiology, biophysics, and structural biology into higher-level theories of the living cell. A single cell-biological theory integrating all lower-level theories would be the ultimate goal. How should this be done?

Biological reductionism gives the following answer. In explaining biological phenomena at some initial level L (e.g. a living cell), first, an inventory of the several classes A_1, A_2, … A_n of phenomena at L (e.g. metabolism, replication, transcription, translation, and transport) must be made. Each class A_i constitutes a level L_i of biological phenomena, and each level L_i is an immediate sublevel of the initial level L. Now, following the reductionist methodology, each level L_i of phenomena is investigated in isolation from all the phenomena at other immediate sublevels of L. Ideally, such an investigation results in a subtheory T_i for biological phenomena at sublevel L_i. Thus we may find adequate subtheories T_1, T_2, … T_n for all immediate sublevels L_i of L. Hence, or so the reductionist story goes, if we combine these subtheories T_1, T_2 … T_n into a single theory, we end up with a satisfactory theory T explaining the biological phenomena at our initial level L.

The real problem has, of course, been hidden in this sunny picture of the reductionist strategy. Each subtheory T_i explains phenomena at sublevel L_i *in isolation from all the phenomena of other immediate sublevels of* L, that is, under certain conditions C_i. Hence, *in vitro* research into a sublevel L_i can only justify the statement: "If conditions C_i apply, then phenomena of class A_i are explained adequately by theory T_i." Obviously, conditions C_1, C_2, … C_n do *not* all apply at level

L. Since influences and interactions with classes of phenomena of other immediate sublevels were ignored during the construction of a subtheory T_i about phenomena of class A_i, subtheory T_i does not necessarily explain phenomena of class A_i in case some of the other classes of phenomena *are* present. It remains an open question to what extent these influences and interactions thwart the application of subtheory T_i at level L. Hence, the "combination" of subtheories T_1, T_2, ... T_n into a theory T explaining the phenomena at level L is a major obstacle of the reductionist strategy, an obstacle that is considered to be insurmountable in principle by antireductionists. Antireductionism claims that the phenomena at level L always have properties that do not hold for any class of phenomena at sublevels of L. Properties having this remarkable characteristic are called *emergent* properties, of which Bruggeman *et al.* (2002) present some examples in Section 7 of their paper.

After these rather dim findings about the reductionist strategy, we may ask: are the subtheories T_1, T_2, ... T_n of any use in the construction of the overall theory T? Avoiding an extreme antireductionist stance, Bruggeman *et al.* opt for a moderate position: subtheories T_1, T_2, ... T_n may be useful for the construction of T. Experimental testing, *in vitro* or, when a computational model of several *in vitro* theories is investigated, *in silico*, to assess the effects of (gradually) relaxing the conditions C_i under which a subtheory T_i holds, should convince researchers of the applicability of T_i at the initial level L.

Nevertheless, the authors expect that an overall theory of a biochemical system of phenomena at level L usually cannot generally be conceived of as a (linear or nonlinear) mathematical function of the theories T_1, T_2, ... T_n of its immediate sublevels. Two emergent properties in particular—"macromolecular crowding" and "channeling"—speak against these reductionist methods and plead for a holistic approach instead: indeed, there are *in vivo* phenomena which cannot be studied *in vitro* or *in silico*. Ideally, such biocomplex phenomena should be measured and manipulated within the living cell. Hence, an *a priori* reductionist stance is not a viable position. On the other hand, experimental results have clearly indicated that the reductionist strategy in some cases *can* be fruitful. Bruggeman *et al.*'s example on yeast glycolysis indicates that, at least for this metabolic pathway, its functioning can be understood in terms of the (*in vitro* determined) properties and interactions of its constituent enzymes. Therefore, an outright antireductionist stance on methodological issues in cell biology will not do as well.

Favoring, on the basis of *a priori* considerations, one method of inquiry to the detriment of the other leads to a biased methodology that shields off unwelcome empirical evidence. Thus, Bruggeman *et al.* make a case for a pluralistic strategy, combining reductionist and antireductionist strategies, thereby making the best of the available evidence. A pluralist approach leaves all options with respect to the organization of classes of phenomena within biosystems open, so that *empirical* considerations, unlike in exclusively reductionist or in exclusively antireductionist approaches, have a final say in choosing the appropriate methodology. It can very well be that, ultimately, we need both reductionist and antireductionist strategies, depending on the classes of phenomena that are being investigated. Cell biologists try to understand the functioning of living cells in terms of their component parts and the interactions among these parts. Understanding should entail mechanistic explanation and functional interdependency. The objective of cell biology cannot be reached if it is not accepted that living systems are complex nonlinear systems, some aspects of which can only be understood by considering the system as a whole.

4. Inter-level relations in psychology: a dynamical perspective

In his contribution, Looren de Jong (2002) notices that the concepts and arguments that were developed in the current debate on reductionism, no matter whether they come from functionalists, eliminativists or "new wave reductionists," fail to accurately describe the actual developments of sciences such as biology and biological psychology.

For centuries, Euclidean geometry and Archimedean statics have prevailed as showpieces of this Aristotelian ideal of knowledge. (In this connection we also have to mention Spinoza's *Ethica* and Newton's *Principia*.) Modern philosophy of science has, of course, departed from the ideal that scientific theories are based on self-evident principles, but its view of a scientific theory as a deductively closed set of true sentences is still going strong. Though 20th-century philosophy of science, which has been dominated largely by logical positivism, has significantly altered our conception of knowledge and science, in large areas of philosophy traditional concepts, such as the idea that scientific "laws" are timeless, context-independent and necessary, still dominate the debates. Moreover, though it is granted that our biological and psychological knowledge is still far from mature, a central topic in the contemporary debate on reductionism is still the question: "If physiology has reached a mature state, what will be the status of our body of folk psychological truths?" Understandably, the discussion has focused on the possibility or impossibility of defining higher-level concepts in terms of lower-level concepts. Let us call the reductionism discussion that investigates the particularities of inter-level reductions of completed higher-level theories to completed lower-level theories "static reductionism." It is static, since *changes* of the theories under consideration are left out of consideration.

On the other hand, we might also look at inter-level relations between incomplete higher-level and incomplete lower-level theories. Only recently, this *dynamic* branch has come to the fore in the philosophy of mind. The recent study of Bickle (1998) is a case in point (in the philosophy of biology, such a dynamic approach was defended by Shaffner, 1993). Nevertheless, this change of orientation has not been radical enough, according to Looren de Jong. In his contribution, he argues that, although Bickle does consider theory change, Bickle's *New Wave Reductionism* put insufficient emphasis on the role of co-evolution of higher-level and lower-level theories that both are in the process of being completed.

In the philosophical literature on biology and cognitive neuroscience, Looren de Jong discerns a new perspective for understanding inter-level relations between developing theories. Obviously, these inter-level relations inherit the tentative character from the theories they connect. Hence, just like the statements in the theories under consideration, the inter-level relations have the status of hypotheses, which may have to be revised if the theories they connect are revised. The function of inter-level relations, therefore, is a heuristic one, in that, during their developments, both the higher-level and the lower-level theory can mutually influence each other by way of the *heuristic* inter-level relations.

Unlike the universal laws of physics, theories are usually constructed for only a restricted domain of phenomena. These restrictions may depend on the circumstances in which these phenomena take place, on the level of abstraction of these phenomena, and on the interests of the researchers. Hence, in, for example, biology, we find a patchwork of theories, each with different explanatory interests and a more or less limited scope. General laws covering all biological phenomena are not to be expected, perhaps not even in "completed" biology. Combining these characteristics leads to a view of explanation that allows for several explanations of classes of phenomena at different levels of abstraction: a pluralistic, domain-specific, multilevel account of explanation.

Interaction between two or more theories covering overlapping classes of phenomena takes place by way of tentative heuristic inter-level relations between concepts of the respective theories. These inter-level relations may, on the one hand, enable us to interpret micro-level phenomena in terms of concepts of the higher-level theory, and, on the other hand, make possible more precise formulations and quantifications of qualitative higher-level theories in terms of phenomena described by lower-level theories. Thus, development and revision of both higher-level and lower-level theories are furthered by heuristic inter-level relations, which may have to be revised in the whole process. In this way, inter-level relations may be used to *extend* the scope of some lower-level theory by tying it up to higher-level theories. Hence, heuristic inter-level relations lead to extensions of existing theories rather than reductions.

5. Conclusion

The debate on reductionism in 20th-century philosophy of mind has focused largely on the *form* inter-level relations between a higher-level theory and a lower-level theory should finally and ideally take. Hence, the history of the recent philosophy of mind comprises a variety of proposals for such a form and counter-examples to such proposals, oscillating from Nagel's "bridge laws" to Putnam's rebuttal of the identity theory, from arguments for type-materialism or token-materialism of various brands and Baker's (1987) thought experiments to counter such arguments. Kim's recent proposals for functionalization fit within the same picture as well. It is to be noticed that much of this type of philosophical research is *a priori*: currently, no single science provides the ideal inter-level relations these philosophers argue about. The fact that these philosophers draw on material from the empirical sciences to support their proposals or counter-examples and the fact that, of course, in an actual reduction the *form* has to be given flesh by way of *empirical* data do not entail that the philosophical project itself has been an empirical, naturalistic undertaking. Instead of investigating varieties of reduction as they actually occur in the sciences, however provisional and deficient they may be, by and large the reductionist debate in the philosophy of mind has been restricted to the *normative* issue of providing a coherent sketch of the form of ideal inter-level relations.

The inquiries into computer science, cell biology and biological psychology showed in the first place that the nature of inter-level relations has to be assessed *empirically* with an eye to the dynamics of empirical research. Close observation of the ever-changing reduction relations in the developing sciences, and revision of philosophical positions based on these empirical observations, may, in the long run, be more conducive to an adequate understanding of inter-level relations than a traditional *a priori* approach. In computer science, it is obvious that not every proposal for a translation between higher-level language L_2 and lower-level language L_1 will do, since the higher-level language has an autonomous semantics that must be retained in a meaning-preserving translation. In cell biology, we may not expect *a priori* that either an exclusive antireductionist or an exclusive reductionist methodology will automatically lead to a correct theory. *Empirical* considerations have to decide between the several alternative types of possible relations between the higher-level theory and the lower-level theories. In biological psychology, inter-level relations must be seen as hypotheses stating relations between concepts of higher-level and lower-level theories, hypotheses that steer and focus research at both levels. Of course, these hypotheses may have to be revised as research develops.

Summarizing, the three articles above make a plea for broadening the scope of the reductionism debate. By actually studying the way inter-level relations grow out of the developing sciences, we will not only make philosophical inquiries more relevant to the sciences, but we will be able to test our philosophical accounts of inter-level relations by confronting them with what really happens in science. Hence, we may construct better instruments for analysing inter-level relations and we will probably gain a better understanding of science itself.

Notes

*The authors appear in alphabetical order.

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