

Enriching Philosophical Models of Cross-Scientific Relations: Incorporating Diachronic Theories*

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1. *Introduction: Simple Reduction and Beyond*

Traditional and New Wave models of reduction in science have not lacked for ambition. Philosophers have presented single models to account for the full range of interesting intertheoretic relations, for scientific progress, and for the unity of science (Nagel, 1961; Oppenheim and Putnam, 1958). Early critics attacked the logical empiricists' proposals about the character of intertheoretic connections (Feyerabend, 1962; Kuhn, 1970). New Wave reductionists have similarly argued that various intertheoretic relations fall at different points on a continuum of goodness-of-intertheoretic-mapping. Still, whatever their differences with the logical empiricists, New Wave reductionists have retained traditional aspirations for a single, comprehensive model of reduction that will make sense of the wide range of intertheoretic relations, of progressive scientific change, and of how the various sciences hang together (Hooker, 1981; Churchland and Churchland, 1990; Bickle, 1998). Both logical empiricists and their New Wave successors proffer such unified, multi-purpose models.

Regardless of the field, multi-purpose tools typically sacrifice precision for versatility. Recent analyses of mechanistic explanation have helped to reveal that these models of scientific reduction are no exceptions to this rule, and the cost of sacrificing precision is one that the mechanists are unwilling to pay. Traditional and New Wave reductionists manifest allegiances

- (1) to the (virtually exclusive) analysis of theories and intertheoretic relations and
- (2) to conceptions of explanatory levels in science rooted in considerations pertaining to the size of and the mereological relations between the sciences' objects of study.

(Discussions of both explanatory levels and mereological relations follow in subsequent sections.)

By contrast, advocates of mechanistic analysis offer detailed accounts of particular systems' functioning that survey their components, their operations, and the larger systems to which they contribute (Bechtel and Richardson, 1993; Glennan, 1996; Machamer, Darden and Craver, 2000; Craver, 2001; Bechtel, 2006). The mechanists' approach to philosophical questions concerning cross-scientific relations is primarily data-driven from the bottom up.

Explanatory pluralism (McCauley, 1986, 1996, [in press]; McCauley and Bechtel, 2001) also eschews a single multi-purpose model of reduction, arguing that considerations and dynamics bearing on theory succession within particular sciences often substantially diverge from those pertaining to cross-scientific relations. The explanatory pluralist welcomes the detailed analyses of specific mechanisms in nature that the mechanists are furnishing as a pivotal contribution to our understanding of scientific explanation in cross-scientific contexts, but surveys additional issues as well. Explanatory pluralism also investigates, across explanatory levels, such matters as borrowing concepts and theoretical strategies, sharing experimental techniques and tools, and, perhaps most importantly, tapping new sources of evidence, especially experimental evidence. Explanatory pluralism emphasizes that because just about

everything about science is so hard to do, cross-scientific opportunism is plentiful (McCauley, 2000 and [in press]).

Explanatory pluralism explores a broader array of considerations and envisions a more wide-ranging framework for the analysis of cross-scientific relations than do mechanistic analyses. Nevertheless, the two approaches are not at odds. They reject both traditional and New Wave reductionists' absorption with laws and theories and the sufficiency of mereological considerations to distinguish levels of explanation plausibly (items (1) and (2) above). Explanatory pluralism, however, also retains a concern for more traditional (top down) reflection on the sciences' overall arrangement. Ideally, mechanistic analysis contributes to filling out the explanatory pluralist picture and provides a means for checking explanatory pluralism's more general declarations about explanatory levels in science. In the light of both mechanists' findings about the various cases they examine and a more fine-grained treatment of the wide variety of cross-scientific relations, explanatory pluralists aim to refine our large-scale conceptions of explanatory levels in science and of how they are connected. By laying out a hitherto mostly neglected distinction between theories and investigations of synchronic, structural phenomena, on the one hand, and of diachronic phenomena (especially larger scale and longer term diachronic phenomena), on the other, this paper aims to advance that "more fine-grained treatment of the wide variety of cross-scientific relations" a bit further.

Section 2 reviews the explanatory pluralist's principal arguments to date against all-purpose models of scientific reduction first and then briefly sketches the resulting view of cross-scientific relations that explanatory pluralism has supplied heretofore. Section 3 enlarges this view, taking inspiration from a distinction between two types of inquiry among the sciences, viz., between the study of natural structures without or at least with little reference to time and the study of natural processes and changes in nature over time. Up to now, philosophical discussions concerning cross-scientific settings have focused almost exclusively on the former. Section 4 explores the more complicated portraits of (1) analytical levels in science, (2) cross-scientific relations (offering a quick illustration from the cognitive sciences of prominent types of intertheoretic and cross-scientific connections that can arise), and (3) reduction.

2. *Some Familiar Reasons Why Reduction in Science Is Not Simple: Distinguishing Between Intralevel and Interlevel Relations*

William Wimsatt (1976) first suggested that behind Ernest Nagel's traditional conception of reduction in science lurked two quite different sorts of intertheoretic relations. Distinguishing between *intralevel* or *successional* reduction (concerned with progress over time within some science) and *interlevel* reduction (concerned with what I have been referring to as cross-scientific relations), Wimsatt maintains that philosophers and scientists (especially those interested in the relations of psychology and neuroscience) frequently confuse their diverging dynamics. (See figure 1.) He has eliminative materialism, in particular, in his sights. Eliminative materialists

insert figure 1 about here

draw inferences about the elimination of psychology and its objects of study (such as beliefs, hopes, and other mental states and, ultimately, the mind itself) on the basis of projections about the emergence of superior neuroscientific accounts of the phenomena to be explained.

Expanding on Wimsatt's objection, I (1986) argued that the problem is that eliminativists come

to these conclusions, because they presume that the comparison of incompatible theories from adjacent explanatory levels (in this case, the psychological and the neuroscientific) at a particular point in the history of scientific inquiry will yield the same results that the comparison over time of incompatible theories from the *same* science yields. In short, presuming a single model of reduction, they apply the lessons that arise from *intralevel* relations to a case of *interlevel* relations.

Not coincidentally, one of the first eliminative materialists was Paul Feyerabend (1967). Feyerabend (1962) and Thomas Kuhn (1962) famously studied theory change over time within particular sciences and, thereby, questioned the logical empiricists' reductive model of progress within a science. The logical empiricists held that scientific progress turned on the discovery of ever more encompassing theories that not only predict, disclose, and organize previously unknown patterns of phenomena but also provide improved accounts of the phenomena that their predecessors explained as well. The new account is superior, if for no other reason than its ability to unify within the framework of a single set of theoretical principles what had previously appeared to be different domains. A well-worn illustration is the ability of Maxwell's theory to manage electrical, magnetic, and optical phenomena at once. Scientists subsequently regard the achievements of diverse earlier theories as special applications of the new, more general theory with which they are now armed. So, Galileo's law of free fall approximates an application of the principles of classical mechanics to falling objects comparatively close to the surface of the earth.

The logical empiricists alleged that the principles of the older theories follow as logical consequences from the principles of the new theory supplemented by a bit of logical machinery dealing with the translation of the theories' predicates. Feyerabend and Kuhn, however, argued on the basis of scrutinizing major episodes in the history of modern physical science that that supplementary translation machinery is overwhelmingly philosophical fiction, that the predicates of succeeding theories do not usually square in any straightforward way, if they square at all, with the predicates of their predecessors, and that change in the sciences frequently involves abrupt, discontinuous shifts in theory and practice. Many, if not most, of science's great theoretical successes do not fit neatly with the view of scientific progress as the accumulation of truths.

His criticisms of the logical empiricists' account of theory reduction in science, notwithstanding, Feyerabend (at least at this point in his career) did not abandon their ideal of providing a single, unified model of the diverse matters that the logical empiricists lumped under the rubric of "reduction." Because he construed the progress marked by the succession of theories in particular sciences over time according to the same principles as the progress scientists achieve when they elaborate and enrich their models by looking to research going on at the same time in sciences operating at different analytical levels, Feyerabend arrived at eliminative materialism, i.e., he sketched a case for the liquidation of psychology and its accompanying ontology in deference to superior explanations at the neuroscientific level.

Clifford Hooker (1981), Paul and Patricia Churchland (1990), and John Bickle (1998) endorse what Bickle calls "New Wave" reductionism. New Wavers *explicitly* propose models of intertheoretic reduction in science that simultaneously aspire to incorporate Feyerabend and Kuhn's insights and to retain the logical empiricists' ideal of a single, multi-purpose model. (For example, an *Ur*-text of this movement, Hooker (1981), is entitled "Toward a General Theory of Reduction.") New Wave reductionists hold that the myriad cases of intertheoretic relations in

science scatter across a continuum from better to worse intertheoretic connections. At one end of that continuum, where one theory or, at least, a theory-analogue, maps well onto another theory, these intertheoretic connections approach the ideal of a classical intertheoretic reduction of the sort the logical empiricists touted (Schaffner, 1967). At the opposite end of that continuum fall the kinds of cases that Feyerabend and Kuhn stressed. There the failures of intertheoretic mapping are sufficiently numerous and severe that any hope of mapping one theory onto another is forlorn. Feyerabend and Kuhn, as well as the New Wave reductionists they have inspired, noted that, without prospects for reconciling the two theories, scientists simply abandon the less accomplished theory and its distinctive ontology. (Consequently and, again, not coincidentally, one of the second generation eliminative materialists was Paul Churchland (1981).) The history of modern science is a history of discarding cherished commitments about what the universe contains. The crystalline spheres, the bodily humors, and the phrenological faculties are all instances of the theoretical flotsam and jetsam that bobs aimlessly in the wake of scientific progress. When old theories cannot be readily mapped onto their superior successors, science *eliminates* both them and all of the stuff that only they discuss.

I (1986; 1996; [in press]) have argued that the elimination of psychology and its objects of study in favor of neuroscience and its objects of study that New Wave models envision and that eliminative materialists extol is implausible. I have pressed both normative and factual arguments. The latter is a simple historical induction. What both the eliminative materialists and the New Wave reductionists have continually ignored is that the dire outcomes they highlight do *not* arise in every circumstance where two theories with overlapping explananda conflict. *All* of the theory eliminations that Kuhn (especially) made famous and that the eliminative materialists seized upon to model the future of scientific explanations of human behavior occur in Wimsatt's *intralevel* settings, i.e., they concern changes over time *within* a particular science. The problem, however, is that the contemporary and future relations between research in neuroscience and psychology about which the eliminative materialists conjecture involve *interlevel*, i.e., cross-scientific, relations.

The (negative) normative point is that the kinds of interlevel inquiries that the psychology-neuroscience case instantiates are not abetted by the elimination of higher level psychological theories, let alone the entire elimination of the psychological sciences from which they spring, which the eliminativists have envisioned in some of their most extreme proposals (e.g., Churchland, 1979 and 1981). This would simply deprive neuroscience of the theoretical and conceptual direction, the experimental techniques, and, most notably, the large bodies of evidence that the psychological sciences provide, to say nothing of largely marooning inquiries at the socio-cultural level from substantial interlevel influences. Following the recommendations of the eliminative materialists and of the application of the New Wave model of reduction to this cross-scientific case would yield a science overall (and a neuroscience!) that possesses far more limited theoretical, practical, and evidential resources, which is to say that it would yield a science overall and a neuroscience, in particular, that are comparatively impoverished. Note, I am *not* saying either that eliminations in science do not occur or that they should not occur but, rather, that with established sciences, such as neuroscience and psychology, they do not occur as the direct result of cross-scientific conflicts of theory.

Wimsatt (1976), Patricia Churchland (1986), and Bickle (1998) have all adopted the language of the "co-evolution of theories" to describe (among other things, in Churchland and Bickle's cases) the on-going negotiations of concepts, theories, and evidence that occur between

scientific inquiries carried out at different levels of explanation in science. The central insight is that eventually scientific research projects carried out at adjacent levels of explanation will inevitably exert selection pressures on one another. All else being equal, scientists prefer theories that are consilient to theories that are not (Wilson, 1998).

The mechanists' analyses of specific explanatory problems, such as Bechtel's account (2006) of the study of cell mechanisms and of the emergence of cell biology in the middle of the twentieth century, supply the kind of detailed examinations of cases that reveal the limitations of the co-evolutionary talk for making sense of interlevel, i.e., multi-level, inquiries. Ultimately, the co-evolutionary metaphor is unsatisfactory, since one of the possible outcomes of the co-evolution of species is the extinction of one or the other or both. But as the mechanists' discussions show, the inquiries in question reliably result in the ever more complex integration of concepts, theories, practices, and evidence between what are, nonetheless, distinguishable analytical levels. (See, for example, Craver's (2001) general model of mechanistic analysis.) *None* of the historical cases of eliminations in science, i.e., the (theoretical) analogues of extinction in the history of science, that either the eliminativists or the New Wave reductionists cite are cases of interlevel relations, and this pronouncement applies even to the putative counter-examples that the Churchlands (1996) have offered. (See McCauley, [in press].) Once *scientific disciplines* (and sub-disciplines such as cell biology) achieve some stability, as marked not only by theoretical and empirical accomplishments but also by social developments (such as the emergence of distinctive disciplinary names and corresponding societies, journals, university departments, etc.), they, in contrast to particular theories that might rule in those disciplines at any specific moment, do not, subsequently, go extinct. Instead, they and their currently prevailing theories add to the ever more richly woven fabric of explanations and accounts of the world that the sciences furnish. They contribute to the variety of analytical and explanatory perspectives that explanatory pluralism emphasizes.

Two qualifications are in order before proceeding in the next sections to a new set of considerations that will only complicate this picture more. First, none of this is intended to slight the fundamental contribution of reductionist research strategies in science. Arguably, no discovery strategy has proven any more profitable than reductionism in the history of science. (Rather, the issues concern getting clear about just what various types of reductions do and do not amount to.) Commentators have, if anything, faulted explanatory pluralists for their *optimism* about the promise of reductionist research strategies (Schouten and Looren de Jong, 2001).

Second, some subsequent writings on matters of the mind indicate that the Churchlands (e.g., P. M. Churchland, 1986 and P. S. Churchland, 1996) have been inclined, at least some of the time, to relax their eliminativism, typically in favor of some version of the psycho-physical identity theory. Neither their subsequent writings on intertheoretic reduction (e.g., Churchland and Churchland, 1996) nor the subsequent writings of other New Wave reductionists (e.g., Bickle, 2003), however, budge in their support for a single, multi-purpose model of intertheoretic reduction. The Churchlands offer some unconvincing counter-examples to the historical argument (McCauley, [in press]), which Bickle's discussions simply ignore. But, crucially, neither take up the normative arguments at all. This is unfortunate. For if the analyses I advance below are on the right track, then all of the philosophers who have written on cross-scientific relations and especially the New Wave reductionists, who have propounded a general, all-purpose model that presumes to supply exhaustive accounts of intertheoretic relations, of cross-

scientific relations, and of scientific progress, have significantly *underestimated* the diversity of patterns that arise in scientific research.

3. *A Further Reason Why Reduction in Science Is Not Simple: Distinguishing Between Synchronic and Diachronic Modes of Scientific Theorizing*

The kind of cross-scientific elimination of theories and of whole sciences that the New Wave reductionists dream about and the kind of cross-scientific (heterogeneous) reductions of *sciences* that Nagel (1961) explicitly discussed are unpromising for an additional reason. To see why will turn on deploying a common enough distinction. It will be useful in thinking about cross-scientific relations to differentiate between *synchronic* scientific theories and research devoted to explaining *structural* phenomena as opposed to theorizing about *diachronic* matters devoted to explaining *processes*, *especially those processes that take place over comparatively long time frames on a comparatively large scale*. This is a distinction between two different modes of scientific theorizing and projects of research to which philosophers writing on reduction in science have given little attention.

That said, I should begin by noting some necessary caveats. This is not to say that diachronic theories have received *no* attention from philosophers interested in cross-scientific relations. For reasons connected with paths mechanistic analyses inevitably take, recent mechanistic discussions have earned the clearest exemption from such a charge. See, for example, Bechtel's discussion (2006, pp. 94-117) of the vital contributions to scientists' understanding of cell mechanisms in the first four decades of the twentieth century that biochemical research on the many *processes* involved in aerobic cellular respiration furnished. As that discussion illustrates, the fine-grained specification of mechanisms requires careful attention to the processes in which those mechanisms are involved. Still, both here and elsewhere in the literature on mechanistic analysis, any discussions of diachronic theorizing that spring up focus overwhelmingly on accounts of short term processes concerning small scale systems. I will return to these issues below.

Analyses of systems' *structures* (including analyzing the structures of mechanisms) concentrate on *compositional* relations. Such analyses decompose systems into their parts. Understanding the operations of systems and mechanisms partially depends upon tracing the spatial relations and the connections among their parts. This is, perhaps, the most transparent illustration of the reductionist impulse in scientific research available, and the philosophical literature on reduction in science is replete with examples. Up to now philosophical discussions of cross-scientific relations have mostly proffered such structural analyses and have, thereby, reinforced most philosophers' conceptions of these matters.

The emphasis in philosophical discussions of reduction on structural theories and compositional relations has been an important impetus for the widespread predilection to use mereological criteria to identify explanatory levels in science (Kim, 1998). The basic intuition is that big things are made of not-so-big things, that those not-so-big things are made of smaller things, and that those smaller things are made of things smaller yet. This is why philosophers so often rely on considerations of scale as a heuristic for distinguishing explanatory levels in science. This leads to what are often far more detailed conceptions of the hierarchical arrangement among the sciences (e.g., Churchland and Sejnowski, 1992, p. 11) than the broad categories employed at the left side of figure 1.

Rooting accounts of explanatory levels in science in a mereological conception of organizational levels in nature, however, generates anomalies. For the physical sciences not only address the smallest and most fundamental building blocks of nature. They are simultaneously concerned with the very *largest* things as well. The basic physical sciences include both the sub-atomic and the astrophysical. So, a scheme for organizing the sciences that looks to mereological criteria inspired by reductionists' preoccupations with synchronic, structural theories results in descriptions that miss at least some of those sciences' projects. (In fact, a strategy for differentiating organizational levels in nature and corresponding explanatory levels in science that relies on *diachronic* considerations does a better job. At least, it readily accounts for the broad hierarchy of the families of the sciences that figure 1 portrays. In short, the operative principle is that the longer the systems some science specializes in have been around, the lower that science's analytical level (McCauley, [in press]).)

The reductionist presumption is that the structures, the patterns, and the principles (that those structures and patterns inspire) at lower levels will suffice to explain the structures and patterns at higher levels and the principles they inspire. Logical empiricists aim to deduce the *principles*, i.e., scientific laws, at higher levels from the principles at lower levels, in combination, of course, with a translation apparatus (mentioned earlier) connecting, as systematically as possible, the predicates the laws include. So, for example, with the aid of appropriate translation machinery, the logical empiricist aspires to reduce the laws of chemical bonding to the laws in sub-atomic physics concerned with the actions of atoms' components. In cross-scientific settings the logical empiricist model seeks to reduce *theories and their laws* by explaining them in terms of the theories and their laws at lower levels of explanation.

As stressed earlier, critics, commentators (Schaffner, 1967), and New Wave reductionists all despaired of ever finding translation machinery sufficient to carry through classical theory reductions. Instead of mapping higher level theories and their principles on to lower level ones, the New Wave reductionists either speak of mapping theory analogues in the hopeful cases or of simply ignoring (if not dispensing with) the higher level enterprises when the explanatory perspectives at higher and lower levels substantially diverge. Although one of my secondary agendas is to discredit these latter proposals, it is the former one about the hopeful cases which concerns me here.

Paul Churchland (1989, p. 49) holds that New Wave theory reduction involves the construction of an "equipotent image" of the higher level, reduced theory within the framework of the laws and principles that the lower level theory provides. But talk of "images" in the context of discussions of *logical* reconstructions of scientific theories and laws is metaphoric. Laws and theories are not the sorts of things that most people entertain *images* of. The emergence and prominence of the metaphor, however, is not coincidental. Careful examination of New Wave work on "theory reduction" over the past couple of decades reveals that rather than reconstructing higher level *theories and laws* at lower levels, New Wave reductionists have often themselves been constructing equipotent images of upper level *patterns and mechanisms* at lower levels. (Examples include Churchland, 1986, chapter 10, Churchland, 1989, pp. 77-110 and 1995, Churchland and Sejnowski, 1992, and Bickle, 2003.)

That New Wave reductionists have increasingly turned to tracing (equipotent) images at lower levels of patterns and mechanisms at higher levels certainly comes as no surprise to the mechanists, whose work, in effect, underscores the fact that the traditional and New Wave focus on scientific laws and theories requires a forced fit, at best, in the biological, psychological, and

(I would add) socio-cultural sciences (Wright and Bechtel, [in press]). These sciences typically traffic in phenomenal patterns and functionally characterized mechanisms (more than in laws) and in increasingly fine-grained models of those mechanisms (more than in broad, general theories). This is not to say that these sciences never involve general explanatory principles or ambitious, sweeping theories (e.g., Llinás, 2001) but rather to indicate that they are the exceptions rather than the rule. Robert Cummins (2000) observes, for example, that most of psychology's principles are not explanatory laws so much as *effects*, i.e., patterns at the psychological level in need of (further) explanation. Reductionists' interests in interlevel relations within and between the higher level families of the sciences, i.e., at levels of explanation higher than the basic physical sciences, mostly concern tracking the *structures and operations of mechanisms* as explanations of higher level patterns rather than tracking the *logical connections (or the lack thereof) between theories and laws*.

Oddly, nothing about the uncontroversial metaphysical principles concerning compositional relations in synchronic, structural studies mandates or even especially favors reductionism. That such an orientation remains as popular as it does is, presumably, a function of its historical success in abetting scientific research. Scientists can, however, just as readily ask questions about the structure of the larger system or pattern to which the targeted part contributes (Craver, 2001). They can not only examine the context in order to ascertain the part's spatial relations and connections to other components, they can also examine the roles it plays in the characteristic processes the larger system exhibits. When researchers have reason to suspect that such arrangements are the results of *selection* (natural or otherwise), looking to higher levels can offer clues about systems' functions and, thereby, suggest criteria for individuating mechanisms on functional grounds as well as on spatial and structural ones.

If they do not perennially operate in the synchronic mode, structural theories, at least, start that way. They look at a system's parts without reference to time. Upon pondering a structure's function, though, whether that of the overall system or of one of its parts, the spotlight can shift to temporal considerations. At each level scientists search for interacting systems that exhibit coincident structural and operational patterns. Machinery in nature can display myriad unanticipated complexities (Bechtel, 2006). The first step back from the machinery's structural intricacies reliably spawns reflection on that machinery's organization, on its functions, and on the processes that contribute to realizing those functions.

Especially in the higher level families of the sciences, where selective forces impinge and, thus, where functional considerations seem to possess greater analytical promise, structural investigations ineluctably prompt inquiries about functions, which in turn inspire investigations into processes and operations, i.e., into *changes* in these systems over time. This is why emphasizing the distinction between synchronic and diachronic phenomena and especially a corresponding distinction between synchronic and diachronic modes of analysis will probably feel somewhat idealized (to those who are sympathetic) or somewhat contrived (to those who are less so). What adds to those impressions is the fact that learning more about a system's structure provides clues about its function and learning more about the accompanying processes can highlight structural details that might have otherwise gone unnoticed. These two sorts of analysis not only provide resources for one another's improvement but often are intimately intertwined. At the finest resolutions in the biological, psychological, and socio-cultural sciences, where considerations of function serve as the fulcrum on which this distinction between these two modes of scientific analysis balances, whether structural, synchronic analysis of a

system, on the one side, or diachronic analysis of the short term processes it exhibits, on the other side, dominate in any explanation can shift back and forth from one problem to the next.

Still, structural, synchronic analyses often leave diachronic questions mostly unaddressed, and when they do take up such matters, the time frames they contemplate, at least *initially*, are of *comparatively short duration*. This is as true about ancient scientists' meditations on the structure of the cosmos (as revealed by celestial bodies' apparent motions) as it is about modern scientists' meditations on the mechanisms of mind as revealed by features of human brains and human performance. Ancient astronomers logged the consequences of the earth's daily and annual motions in the apparent movements of objects in the heavens for nearly two millennia before Hipparchus in 129 BCE recognized the precession of the equinoxes, the effect of a third wobbling motion of the earth around its axis, which takes nearly 26,000 years to complete a single cycle. Psychologists, neuroscientists, and cognitive scientists, until quite recently, spent more than a century overwhelmingly preoccupied with structural models of the mind/brain and with evidence concerning its changes and operations over very short durations that rarely even extended to the length of the normal human life span. (Often the study of any processes that structural analyses occasion are also of comparatively narrow *scope*. Patricia Churchland (1986), for example, opens the tenth chapter of her landmark book, *Neurophilosophy*, with a discussion of the relative dearth of theorizing in neuroscience and of the exceedingly fine-grained focus of most work in that field.)

Of course, with respect to scientific theorizing and research on *patterns of great duration* in the biological, psychological, and socio-cultural sciences, Charles Darwin (1859/1979) is *the* pivotal figure. Darwin's greatness arises not only because he furnished modern science with a process, natural selection, that explained why biological systems can be profitably understood as carrying out functions without necessarily engendering worries about illicit teleological ascriptions. His theory of evolution by natural selection also *substantially expanded the time frames* that scientists consider when they theorize about the forces that have shaped not just the biological world but also the human mind.

Addressing long trajectories across natural history, Darwin's theory also requires *a new unit of analysis*. That analytical unit, a *species*, is extended in time and includes countless individual organisms. Darwin's theory of evolution infused the notion of a species with a *theoretical-explanatory* salience that it had never possessed before. Its new found salience for theorizing on the diachronic front also far exceeded any interest the concept might have attained on the structural front theretofore. (In a biology of impregnable boundaries between species, large-scale structural relations are little more than curiosities, and they certainly offer no clues about patterns of descent.) The salience of species for diachronic theorizing has also served as a prominent wellspring for whatever theoretical interest this notion possesses on the structural front since. The subsequent synthesis of Darwinian evolution and modern genetics supplies detailed theoretical grounds for why recurrent structural features in a species' members can now be said to offer clues about what was once presumed to be an underlying "nature" that they share but is now explicated in terms of the similarities of their genomes.

The new emphasis on this large scale unit of analysis (species) does not debar interest in the smaller scale systems (individual organisms) that make it up. *Both* are perfectly appropriate objects for diachronic theorizing. The distinction in biology between ontogeny and phylogeny has, during the past few decades, served as a template for diachronic theorizing in the psychological sciences. The analogue of ontogeny is individual psychological development. As

with the other sciences, diachronic interests first erupted into full-blown theorizing in scientific psychology with the study of relatively shorter time frames. Developmental psychology studies individual humans and, for example, their cognitive functioning across comparatively short time spans, typically no more than childhood, though sub-disciplines concerned with adolescents, young adults, and the elderly have also arisen. (Presumably, such inquiries, in principle, examine no more than the full human life span.)

In psychology as with most of the other sciences, it has taken longer for systematic diachronic theorizing about the forces that impinge over immense time spans to emerge. The phylogeny of the human species is the analogue at the level of biological theorizing for the evolution of the distinctively human mind at the psychological level. Here the interest is in those demands that, over great expanses of time, have shaped the structure and functioning of the minds of the ancestors of contemporary human beings. In the past two decades theories about what has come to be known as evolutionary psychology have emerged as the analogues of phylogenetic proposals in biology (e.g., Tooby and Cosmides, 1989 and 1992). Evolutionary psychologists submit hypotheses about likely selection pressures that would have shaped the human mind for the longer term and conjectures about their expected implications for the *structure* of the modern human mind. Here too theories about long-term (large-scale) diachronic patterns impart new found significance to debates about the mind's structure. The suggestion is that careful consideration and probing of, among other things, contemporary human behavior and mental life should yield evidence for these conjectures. Evolutionary psychologists contend that the resulting recurrent structures in the minds of individual *Homo sapiens* provide clues about underlying similarities of those individuals' genomes just as recurring structures in their bodily organs do. (This need entail neither genetic determinism nor a detailed genetic blueprint for the mind, though it does envision a comparatively fixed cognitive architecture that results from a characteristic developmental sequence across a broad range of divergent circumstances.) Such patterns in human mental life help identify plausible candidates for what might be broadly called "natural" features of the human mind. Such proposals have inspired dozens of new programs of experimental research (Buss, 1999).

In the face of their contentions about the evolution of the mind, of their comments on the unity of science, and of their insistence that no inquiry is "autonomous," that John Tooby and Leda Cosmides sometimes prove reluctant to acknowledge the importance of evidence about the structure and functioning of human *brains* for these matters is both puzzling and unfortunate (1992, pp. 19-24 and 65-66, respectively). Even the most preliminary exploration of the role of research on and theorizing about such diachronic matters will suggest that there are more cross-scientific influences than have generally been dreamt of in the philosophies of many philosophical champions of scientific reduction and, perhaps, of Tooby and Cosmides as well.

4. *Complicating Reduction*

Distinguishing between synchronic and diachronic modes of analysis in the various sciences and further distinguishing, among the diachronic analyses, between short term processes in small scale systems, such as the exceedingly brief influence of the visual icon on cognitive processing (Sperling, 1960) and extremely long term processes in large scale systems, such as the evolution of maturational proclivities in members of our species to acquire natural language (Pinker, 1994), complicates accounts of (1) analytical levels in science, (2) cross-scientific relations, and especially (3) theory reduction. Following are brief comments on each, in turn.

Introducing these distinctions suggests a more refined vision of analytical levels in science. Attention to these distinctions requires adding a third dimension to the picture of analytical levels that figure 1 furnishes. Figure 2 retains figure 1's resources to represent both

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intralevel relations (in the arrow of time across the bottom) and the interlevel relations between synchronic, structural theories (in the front plane for each of the families of the sciences). Figure 2, however, also depicts a third dimension, which permits the representation of theorizing and research in the diachronic mode. Research in the diachronic mode addresses two different time frames (at least) and, correspondingly, systems at two different scales. Thus, figure 2 contains *two* additional planes at each level of analysis. They represent the distinction between theories about the workings of small scale mechanisms in short term time frames and accounts of change in large scale systems over much longer periods of time. The first sort of diachronic project B for example, research in developmental psychology on children's growing command of theory of mind (Wellman, 1990) or research in neuroscience on long-term potentiation (Lynch, 2000) B is represented in figure 2 for each of the families of the sciences by the planes at the back. The second sort of diachronic project, which in psychology, has emerged as a *bona fide* sub-discipline in the past decade, is represented in figure 2 for each of the families of the sciences by the plane that is in between the other two. (The specific theories, models, and sub-disciplines situated in figure 2 are a disparate lot. The aim is only to illustrate the kinds of theories and research that the three planes represent within each family of sciences and the points in time that they arose.)

The most obvious implication of this more complex characterization of the varieties of theorizing and research that go on at each analytical level in science is that it *increases* the number of locales from which intertheoretic and cross-scientific influences can arise. Again, if your reflexive response is to suspect that this rather idealized account misses how much considerations of *function* in systems shape our understanding of their *structures* (and vice versa) or how, for example, our growing knowledge of the molecular structures of the mechanisms of heredity has influenced our understanding of ontogeny (and vice versa), fear not! for *highlighting such bi-directional influences between diachronic and synchronic projects is just the point!* What this more intricate picture of scientific endeavors at each analytical level makes clear is just how many more loci are available for cross-scientific influence, evidence, and inspiration, and examples of all of these possibilities abound. Perhaps most prominently of all, Darwin's theory of biological evolution on the basis of natural selection has served as the model for most subsequent theorizing about large scale change over the long term in both the psychological and the socio-cultural sciences (e.g., Boyd and Richerson, 2005).

Limitations of space permit only a cursory review of some connected examples within cognitive science. Among Noam Chomsky's early proposals (1965, 1972, and 1975) were the claims that linguistics is best conceived as a sub-discipline of psychology and that human beings are innately endowed with a task specific language acquisition device, i.e., a system of principles that constrains the forms of possible natural languages. In effect, Chomsky advanced a theory about some of the human mind's standard equipment.

These proposals invited psychologists of language to undertake psycholinguistic experimentation to test them. Those tests of what is, at its core, a structural theory often concerned the theory's implications for linguistic processing, i.e., for diachronic patterns concerned with local operations such as an application of a passive transformation. Ironically, Chomsky did not accord vast attention to the (mixed) results of this work (Abrahamsen, 1987; McCauley, 1987; Reber, 1987). So, Chomsky's many pronouncements about the place of linguistics within psychology notwithstanding, it is linguists and psychologists who are basically unsympathetic to his theories that have most thoroughly explored the connections between research in these two disciplines (Lakoff, 1987; Langacker, 1987; Gibbs, 2006).

However inert the connections between Chomsky's theories and most research in psycholinguistics has proved, his unwavering nativism concerning the language acquisition device and Jerry Fodor's (1983) related proposal about innate modules that constitute the mind's input systems were among the influences that inspired new *diachronic* theorizing within psychology. (Not all of that theorizing is sympathetic to their views, e.g., Deacon, 1997.) For the past two decades evolutionary psychologists have formulated diachronic proposals about the selection pressures that might be responsible for recurrent features of the minds of contemporary human beings. Although these proposals have proven both suggestive and controversial, I wish here to stress but a single point. These diachronic speculations have, in turn, inspired new hypotheses about the mind's *structure*. Evolutionary psychologists have proposed that the mind is not merely modular at its periphery, as Fodor suggests, but is, instead, *massively* modular (Barkow et al., 1992; Pinker, 1997; Plotkin, 1998). A survey of the various inventories that Tooby and Cosmides (1992) supply suggests that the modern human mind possesses scores of domain specific capacities at the very least. They readily appeal to research in experimental psychology concerned with the structure and functioning of various domain specific systems that their large scale, long term diachronic theory predicts, for example, systems governing disgust reactions and the avoidance of contaminants (Rozin et al., 2000).

Chomsky and Fodor's resuscitation of nativist theories in the cognitive sciences and the evolutionary psychologists' even bolder conjectures about such matters have come in an era when new bodies of evidence have emerged in sciences as diverse as molecular genetics, primatology, and experimental psychology that enable researchers to assess empirically those theories' commitments, both structural and diachronic. For example, on the basis of a review of the available *archaeological* evidence, Steven Mithen (1996) argues not only for a different account of the quasi-modular architecture of the contemporary human mind but an alternative view of its evolution over the past sixty thousand years. In short, Mithen argues that Tooby and Cosmides' Swiss Army knife conception of the mind does, indeed, characterize the mind of *Homo sapiens* during much of the Pleistocene but that archaeological investigation supplies compelling evidence for subsequent evolutionary developments in human cognitive capacities during the last sixty or so millennia resulting in a mind possessing what Mithen calls "cognitive fluidity" between otherwise largely modularized capacities.

Even this speedy overview of but a tiny sliver of the speculations and research during the past few decades in the psychological and cognitive sciences reveals intertheoretic influences that go back and forth between the three types of scientific projects that the planes in figure 2 represent. But not only do diachronic projects influence structural ones within the same family of sciences, diachronic theories and research also exhibit cross-scientific influences *between* the families of sciences. Consider, for example, the fruitful interactions between psychological

research on cognitive development and research on neural development (Munakata et al., 2004).

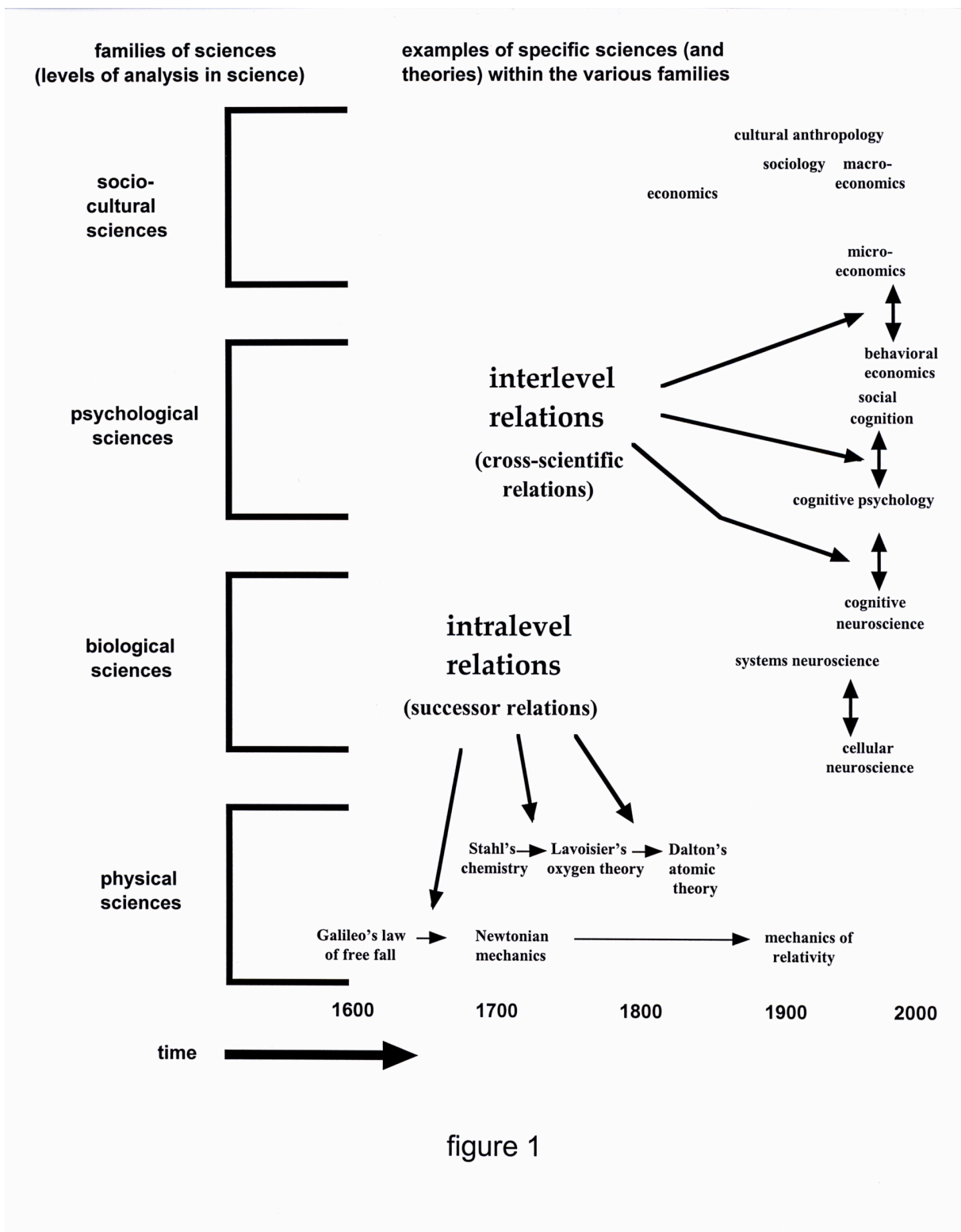
What impact should these considerations have on rethinking reduction? I end with three observations. First, even traditional accounts of reduction that pertain to structural matters suggest at least one plausible analogy for thinking about cross-scientific relations between theories and research in the diachronic mode. The "reductive" strategy here would be to show how our understanding of change at a higher level can be amplified and enhanced by looking both at changes at lower levels and at our best models of them. Analogy, however, is not identity. As the battery of statistical tools that have been developed for such purposes indicate, differentiating and analyzing the relationships of *component processes* looks like a considerably more difficult and complicated task than differentiating and analyzing the relationships of component structures and mechanisms.

Second, because cross-scientific relations often involve *evidential* connections bearing on scientific justification, reductive proposals suggesting that these connections are merely heuristic or peripheral or inconsequential from the standpoint of epistemology miss the mark, even on conservative accounts of scientific progress. Since nearly all of the participants in these discussions are *naturalists* in the philosophy of science, it is all the more perplexing that their proposals would also exclude or downplay the contributions of theories and research about diachronic matters in psychology. Consider, for example, the provocative implications for future research in neuroscience of the discovery of developmental prosopagnosia (e.g., Barton et al., 2001). In such a light the future science of human brains, behavior, and mental life that some reductionists in philosophy envision looks all the more impoverished.

Finally, pondering the place of scientific work in the diachronic mode only reinforces the pragmatic morals of explanatory pluralism. Exploring cross-scientific connections of all sorts is a valuable strategy of discovery at every explanatory level in science that enables researchers to find and exploit new theoretical and evidential resources. Reduction is a priceless tactic in science, but that is not the same thing as a metaphysical program and it engenders no reasons to anticipate the dispensability, let alone the eradication, of sciences.

The additional intertheoretic and cross-scientific relations that distinguishing between science in its diachronic and synchronic modes introduces augur not for simpler models of reduction but for more complicated ones.

* I wish to express my gratitude to Huib Looren de Jong for helpful comments on an earlier draft of this paper.



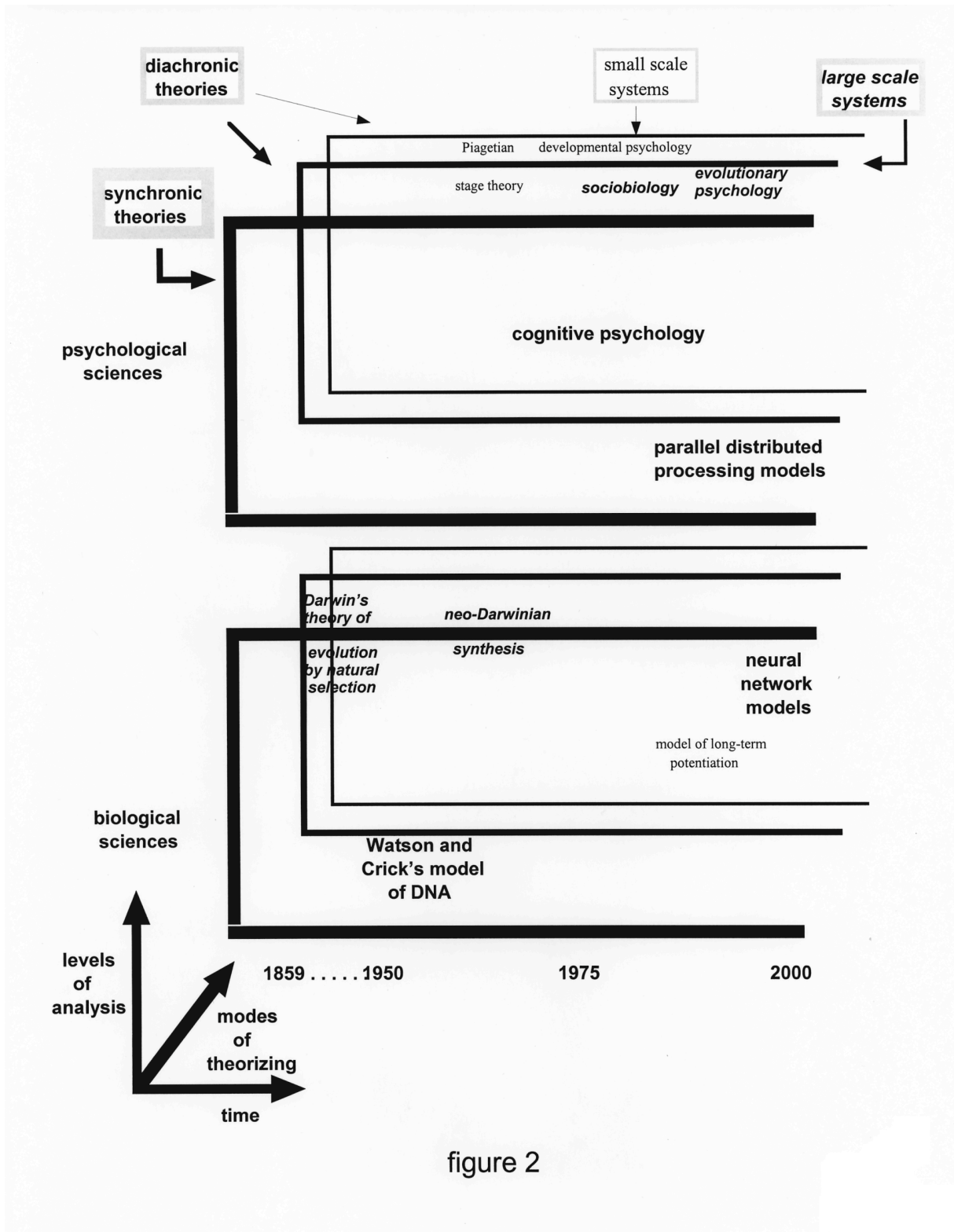


figure 2

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