Biological Complexity and Integrative Pluralism

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Introduction

In a variety of scientific disciplines, political discussions, and social policy forums, there is increasing interest in diversity as an inherent good. Stifling the voices or participation of underrepresented ethnic or economic groups is tantamount to giving up democratic ideals. While there have been trends toward "big science," collapsing scientific research into one or a small number of tracks, diversification of projects funded is associated with potential for creative breakthroughs. Indeed, the National Science Foundation's mission statement acknowledges, "The needs and opportunities of the science and engineering enterprise come in all shapes and sizes. The challenge to NSF is to meet these needs and pursue these opportunities in ways that are appropriate in each case" (National Science Foundation 1995). Since the establishment of the Convention on Biological Diversity, the variety and variability of life itself has been deemed of "intrinsic value." Yet the attitude of deeming diversity of any kind a prima facie good has prompted justified concern about sliding down a slippery slope to complete relativism with an accompanying loss of critical standards in all these domains.

In science, the debate is reflected in a dispute about the unity or disunity of science. In this context, reductionists hold a set of beliefs and methodologies aiming to reduce the diversity of explanations to a small number of theories or laws at a privileged level of discourse, thereby globally unifying science. This standpoint has been resisted by many who investigate higher-level phenomena and represent the knowledge gleaned of psychological properties or biological properties in ways that appear to be devalued by reductionism. They support some type of pluralism and disunity. Philosophers of science have attempted to help settle the debate by clarifying the grounding of both sides. Unity is apparently entailed by strong critical standards based on metaphysical and methodological monism (see Chapter 6, section 6.1). And yet, the reduction of psychology to neurobiology or biology to chemistry and chemistry to physics has never been realized in practice. This failure of philosophical analyses that support unity through reductionism and monism to match the practice of science has led some to consider alternatives to unity. However, disunity can seem to rest on forms of pluralism that verge on an uncritical, "anything goes" leniency (see Galison and Stump 1996 for a range of pluralistic views). Even if one rejects the extreme pictures of a rigorous, reduced, and unified science or a relativistic, pluralistic, and disunified science, there are many places to occupy in the middle ground. Which pluralistic picture of scientific practice should be endorsed, and what are the critical standards retained? The following chapters investigate that territory and defend a framework for a critical pluralism. The main argument is that the complexity of the subjects studied by the various sciences and the limitations of our representations of acquired knowledge jointly entail an integrative, pluralistic model of science. It is a model that allows but does not demand reduction. It is a model that recognizes that pluralist ontologies and methodologies are required to give an accurate picture of science as currently understood and practiced.

The "fact" of pluralism in science is no surprise. On scanning contemporary journals, books, and conference topics in some sciences, one is struck by the multiplicity of models, theoretical approaches, and explanations for the phenomena of interest. For example, there is a host of alternative models and explanations for division of labor in social insects. Division of labor refers to an intricate set of behaviors that may involve thousands of individual ants, bees, or termites engaged in a variety of tasks, including cleaning, raising the brood, tending to the queen, building a comb or nest, guarding, and foraging. It has long been known that there is a temporal component to the tasks; younger workers perform in-nest tasks, older individuals do outside jobs. Some workers specialize and others are generalists, and the colony as a whole responds to changing needs by reallocating workers to the jobs that address those needs. Accounts of division of labor have included group, individual, and "selfish gene" adaptation explanations that appeal, respectively, to claims of ergonomic or other forms of optimization (Oster and Wilson 1978; Wilson 1971; Winston 1987); proximate mechanisms of juvenile hormone regulation and the development of specialized morphological features (Robinson et al. 1989); and variant models of emergent self-organization (Deneubourg et al. 1987; Page and Mitchell 1991; Page and Robinson 1991; Robinson and Page 1989a; Seeley 1989, 1995; Tofts and Franks 1992).

If science is representing and explaining the structure of the *one* world, it is reasonable to ask why there is such a diversity of representations and explanations in some domains. One response is that this simply reflects the immaturity of the science (Kuhn 1962). Yet history shows us that many sciences never exhibit a diminution in the multiplicity of theories, models, and explanations they generate. This "fact" of pluralism, on the face of it, seems to be correlated not with the maturity of the discipline but with the complexity of the subject matter. Compared with theories of social insect biology, there appear to be fewer alternative models of chemical bonding or particle dynamics, while studies of complex human social behavior display an even larger range of alternative views. Rather than explaining away the current pluralism as symptomatic of immaturity, we should invert the order of allegiance. The diversity of views is not an embarrassment or sign of failure, but rather the product of scientists doing what they must do to produce effective science. Pluralism can simply reflect complexity. But what type of pluralism? What type of complexity?

Pluralism in scientific theory and practice has certainly been studied and advocated before. As a result of historical investigations of scientific methods, Feyerabend was led to defend epistemological anarchism (1975, 1981). He endorsed any method as being as good as every other in generating acceptable scientific results. Like Feyerabend's, the most recent defenses of pluralism in science have launched their accounts from an epistemological perspective. Feminist stance theory, for example, grounds pluralism in a perspectivalism based on individual and group social experience (Harding 1986; Longino 1990). Other disunity supporters argue from the partial character of descriptions or diverging areas of interest of the researchers (Cartwright 1980, 1982, 1989, 1994; Dupré 1983, 1996). In contrast, a few have linked pluralism with ontological views about natural kinds (Dupré 1983, 1993; Hacking 1996). While my approach draws on many of the insights of these philosophers, it differs from them in

- grounding pluralism jointly on metaphysical and epistemological arguments, and
- appealing to complexity as a critical tool for understanding the nature and limits of diversity in scientific methods and representations.

The conceptual framework developed in this collection of essays has three practical results: (1) it should allow one to better sort between spurious and real disputes in science; (2) it should provide a taxonomy of typical kinds of conflict, emphasizing a distinction between representational and substantive conflict; and (3) it should allow a better understanding of different kinds of compatibility and complementarity between alternate theories.

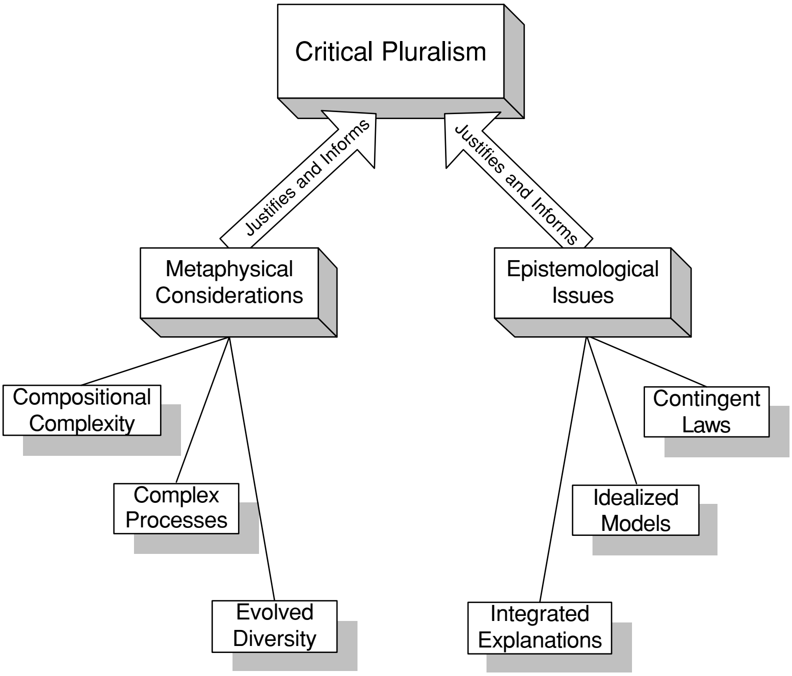

Figure 1.1. Argument structure of the book.

Figure 1.1 shows the basic structure of the argument of the book.

PART I: COMPLEXITY

The first part of the book explores the left side of this picture, that is, the nature of complexity in the world. Current definitions of complexity number somewhere between 30 and 45 (at least according to Horgan's report of Yorke's list; see Horgan 1996: 197, n. 11; see also *Science* 284 (2 April 1999). The multiplicity of definitions of "complexity" reflects not confusion on the part of scientists but the actual variety of ways that systems are complex. In this chapter I outline a taxonomy of complexity for biology. In Part I of the book I explore some characteristics of these different species of complexity, with special attention to the example of social insect colonies. Complexity can be categorized as follows:

- *Constitutive complexity:* Organisms display complexity of *structure*, the whole being formed of numerous parts in nonrandom organization (Simon 1981; Wimsatt 1986).

- *Dynamic complexity:* Organisms are complex in the *processes* by which they develop from single-celled origins to multicellular adults (Goodwin 1994; Goodwin and Saunders 1992; Raff 1996) and by which they evolve from single-celled ancestors to multicellular descendants (Bonner 1988; Buss 1987).
- *Evolved complexity:* The *domain* of alternative evolutionary solutions to adaptive problems defines a third form of complexity. This consists of the wide diversity of forms of life that have evolved despite facing similar adaptive challenges.

I discuss each of these categories in brief detail here and develop these ideas further in the chapters that follow.

A. Compositional Complexity

Minimally, complex systems can be distinguished from simple objects by having multiple parts that stand in nonsimple relations. That is, there is structure or order in the way in which the whole is composed of the parts. Individual cells constituting a multicellular organism differentiate into cell types and growth fields (Raff 1996). The collections of species that form an ecosystem occupy different niches and perform different functions for sustaining ecosystem integrity (Krebs 1994). Individual insects that make up a colony behaviorally differentiate into task specialists and age castes (Wilson 1971; Winston 1987). Indeed, invoking the analogy between individual organism and social insect colony has a long history marked by the use of the superorganism metaphor. In Chapter 2, I argue that invoking this metaphor for explanatory purposes may carry with it conceptual baggage that obscures the variety of compositional structures that describe social insect organization. Indeed, a similar variability in composition rules applies to individual organisms (Buss 1987).

Ecosystems, too, constitute compositionally complex systems, consisting of various nonliving, abiotic, and living, biotic components. The abiotic components of an ecosystem include various physical and chemical factors, while the biotic components are the array of species and organisms present. There are clearly different ways to compose an ecosystem, with different species occupying similar niches or a different total number of components, while maintaining the functioning of nutrient and energy cycling through the system. The variability of compositional complexity generates problems for representing such systems in scientific models and explanations (see also Wimsatt 2000).

B. Complex Dynamics

Complexity has recently become closely associated with nonlinear mathematical functions representing temporal and spatial processes. This type of process complexity is linked with a number of dynamical properties, including extreme sensitivity to initial conditions, self-organizing and recursive patterning (e.g., thermal convection patterns), and negative and positive feedback regimes (amplification and damping) (Nicolis and Prigogine 1989). The striking discoveries of the generality of the models of complex dynamical processes found in basic chemical and physical systems has led to their increasing application to biological systems. For example, self-organization processes are ones in which higher-level order emerges from the simple interactions of component parts in the absence of a preprogrammed blueprint. The bifurcation of ant trails to a food source (Nicolis and Deneubourg 1999) and the emergence of division of labor (Page and Erber 2002) are examples. Holland's theory of complex adapted systems and Kauffman's dynamical models are attempts to describe generic features of systems that engage in such processes (Holland 1995; Kauffman 1993, 1995).

Simulations and empirical investigations into the behavior of social insects investigate these dynamics at a more concrete level (Deneubourg et al. 1987; Page and Mitchell 1991; Tofts and Franks 1992). In Chapter 3, I present models of self-organization for honeybee division of labor developed by Robert E. Page, Jr., and me. Self-organization refers to any set of processes in which order emerges from the interactions of the components of system without direction from external factors and without a plan of the order embedded in any individual component. The mechanisms of self-organization might be analyzed in terms of negative and positive feedback regimens. In Chapter 6, section 6.3, I compare the Page and Mitchell models with other self-organization models of division of labor in social insects and argue that which models are applicable depends on specific evolved features of the system. It is here that I defend the view that a plurality of models may be required to explain what is taken to be the "same" feature of the world instantiated in different individual systems.

Other complex dynamics of bifurcation and amplification are common in complex biological systems. In particular, ecosystems, with their multiple causal components, display discontinuous change that can be modeled by nonlinear equations (Holling 1986). As disturbing influences on an ecosystem increase, they can induce a major change in the organization and functioning of the system in unpredictable ways. A small increase in the disturbance, under certain conditions, can generate catastrophic effects, while at other times generate only correspondingly small changes in the system. An example is in coral reef degradation. There appear to be two stable equilibria states, one dominated by coral, the other dominated by macroalgae (Hatcher et al. 1989). The switch between these two states, a bifurcation, has been identified as a phase change (Done 1992) and has multiple causes operating at different time scales (e.g., storms and toxic pollutants, as well as long-term consequences of overfishing). The dynamic complexity is displayed by the fact that disturbed areas of coral ". . . can recolonize without passing through a macroalgal phase, or they may enter a macroalgal phase which they retain indefinitely" (Done 1992: 124).

C. Evolved Diversity of Populations

The third sense of complexity found in biology is exhibited by the diversity of organisms resulting from their historically contingent evolution. Given the irreversible nature of the processes of evolution, the randomness with which mutations arise relative to those processes, and the modularity by which complex organisms are built from simpler ones, there exists in nature a multitude of ways to "solve" the problems of survival and reproduction. Earlier "solutions" have downstream effects on the types of evolutionary change accessible in the future.

Ecology, again, provides cases. The classic example is of marsupial species populating Australia while placental species of similar ecological role, such as the kangaroo and the antelope, are found elsewhere. Why are marsupials so concentrated in range? The best hypothesis is that marsupials constitute a stable body plan that originated in Australia and came to concentrate on that continent as a result of land separation that preceded their evolution. The convergent evolution of similar placental and marsupial species marks different, equally good, solutions to similar selective environments.

In Chapter 3 I detail the structure of evolutionary explanations that account for this type of diversity of adaptation. There is a concomitant diversity in the scientific accounts of adaptation. The alternative representational frameworks we have in which to record the evolutionary history of life on the planet, as well as the different explanatory questions that are raised in the scientific exploration of that evolved diversity, generate some of the pluralism we observe in contemporary biology. The discussion of genic versus multilevel selection models concerns causal complexity, while the discussion of biological function and its multiple meanings investigates methodological pluralism.

PART II. PLURALISM

The second strand of the argument for critical pluralism focuses on the epistemological and cognitive components of scientific knowledge. The aim for the unity of science draws much intuitive support from a picture of the world as ordered by laws. If we were to find the presumably few, basic laws that govern the events that unfold in our world, we would be in a position to efficiently explain, predict, and intervene successfully in that world; so the unity of science by reduction claims. The traditional philosophical accounts explicate knowledge of laws as knowledge of contingent, universal, exceptionless truths. Thus, one would reason, even if the world were complex, the underlying organizing causal structures are not. If science actually discovered the kind of laws that philosophers have so carefully considered, then we would be able to do all the scientific chores that are described above. But such laws are few and far between. In Chapter 5, I develop an alternative to the traditional philosophical picture of laws, which I identify as a pragmatic conception of laws. This account has the following virtues. It both is a more accurate account of actual scientific knowledge claims and provides a richer conceptual framework in which to locate and compare the variety of knowledge claims that constitute scientific knowledge. My argument here rests on both the metaphysical complexity detailed in the first part of the book, the idealization and partiality that characterize our representations of knowledge, as well as the diverse interests that are served by that knowledge. My pragmatic conception of laws does not rule out universal, exceptionless regularities but broadens the concept of "law" to one that is both more accurately descriptive of what scientists use for prediction and explanation and is compatible with critical pluralism.

In Chapter 6 the question of pluralism versus unity in science is considered directly. Clarification of the places to stand in the unity/disunity terrain is provided. Here I consider an existing model of pluralism in biology, Sherman's (1988) levels of analysis. His approach is a development of Ernst Mayr's (1961, 1982) distinction between "how" and "why" questions and Nikolaas Tinbergen's (1963) four questions for ethology. A levels of analysis model of pluralism acknowledges that different types of questions require different answers and hence might not be in conflict. While there are valuable insights in this approach, the levels of analysis framework fails to adequately represent the relations between alternative explanations. It misconstrues where conflict does and should occur and where alternatives are correctly judged to be compatible. In the extreme case, it can lead to a form of isolationism that can impede answering questions within any single level. The mistake lies not in recognizing a diversity of questions – indeed, scientists do pose a variety of questions to the subjects they study (see Van Fraassen 1980) – but rather in the assumptions made about the epistemological structure of the answers.

A more promising model of pluralism can be forged from understanding that causal models are abstractions that will always remain idealizations. By making simplifying assumptions regarding the noninterference of other potential causes, causal models describe only what would be expected in idealized circumstances (Levins 1968). This conception of theories helps to explain how it can be that models of different causal factors qua models do not directly conflict. In addition, I argue that even if the models may be jointly consistent, in the application of models to the explanation of a concrete case, conflict can arise (see also Chapter 2). In actual cases, multiple causes are likely to be present and interact, and other local elements may also contribute to a specific causal history. Thus in explanation, models of variant possible contributing factors must be integrated to yield the correct description of the actual constellation of causes and conditions that brought about the event to be explained.

Chapter 6 also investigates the philosophical defense of disunity developed by John Dupré (1993, 1996). He argues that metaphysical materialism is, by itself, insufficient to support unity of science by reduction. He suggests that the addition of an assumption of causal completeness at the physical level is required to draw the conclusion that all sciences are ultimately reducible. Yet he argues that we should reverse the inference and take the failure of successful reduction to lead us to reject causal completeness. While I agree with his rejection of reductionism, I argue that his analysis fails to sufficiently acknowledge the nature of scientific representations. In contrast, I suggest that while a well-grounded critical pluralism is materialistic, it is structured by both metaphysical complexity and features of our representations of that complexity.

The investigations in the chapters that make up this book allow the development of a constrained, critical pluralism of scientific theories and explanations. The debate between global unity of science through reduction to a single representational framework or ontological level versus a disunity of incommensurable alternatives is then recast to allow a more refined assessment of where unity can and should be forged and where diversity can and should be championed. In conclusion, critical pluralism as a perspective about the shape of scientific practice is defended. Should the current diversity of laws, models, and explanations in science be viewed as grist for the unifier's mill, raw material to be worked into a single, unified theory of everything? Or should some form of pluralism be not only expected but required for effective scientific practice? This book answers these questions through an analysis of the complexity found in nature and the structure of the representations that scientists devise in order to make sense of that complexity. In the end, the question of the unity or disunity of science can be more rigorously posed and, therefore, more adequately answered. Unification takes place by means of the integration of different theories and models that address partial causes that contribute to the generation of biological phenomena. It is not always to be found in a decreasing number of explanatory theories, but in many cases, quite the contrary. As we decompose multicomponent, multilevel, evolved complex systems into their constituent parts and processes and study these in more detail, more, rather then fewer, models will be the consequence.