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Introduction

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1. Introduction: mechanism and the mechanical philosophy

In many areas of biology, explanations require the discovery of mechanisms. This fact prompts several philosophical and historical questions. Among the philosophical questions are: What is a mechanism? What distinguishes good mechanistic explanations from bad? What is explanatory about finding a mechanism, and how are mechanistic explanations different from other kinds of explanations? Are biological mechanisms relevantly similar to mechanisms in physics and chemistry, or are biological mechanisms in some way distinctive? What are good strategies for discovering mechanisms? What role do diagrams and simulations play in representing and reasoning about mechanistic models? Among the historical questions are: How did biology come to embrace the search for mechanisms? How do the notion of a mechanism and the ideals of mechanistic explanation vary across historical contexts and fields of biology? And how do scientists and philosophers in different historical periods relate the search for mechanisms to austere metaphysical commitments about the structure of the world? These are, of course, large and largely underexplored questions. The purpose of this special issue is to bring together historical and philosophical perspectives to frame and address these questions about the importance of mechanisms to biology. Some of the papers were presented originally at the Second Reichenbach Conference at Washington University in St. Louis, Missouri, 7–9 November, 2003. Others were solicited to round out the focus on specifically biological mechanisms and to present additional perspectives. All papers were reviewed and rewritten for this special issue.

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Biology has often been an addendum to discussions of the mechanical philosophy that focus primarily on physics. In the history of physics, this mechanical philosophy is commonly associated with a restrictive ontology, in which all phenomena are explicable in terms of conservative exchanges at local interactions. Although historians do not agree on exactly when this idea ultimately faded from currency, or on what phenomena ultimately showed its limitations (for example, elasticity, gravitation, electromagnetism, and quantum effects), most agree that the mechanical philosophy, so construed, is no longer tenable in contemporary physics. From the perspective of biology, however, one might tell a triumphal story of the success of mechanism over various forms of vitalism, as well as over biological theories appealing to intelligent design. Indeed, one cannot open a journal in any field of contemporary biology without encountering appeals to the mechanism for this or that phenomenon. This raises several questions: How is the emphasis on mechanisms in contemporary biology related to the mechanical philosophy in the history of physics? Does the notion of mechanism in contemporary biology carry the austere metaphysical commitments of its historical predecessors? Does it share their limitations? Answering these questions requires sorting out the many uses of 'mechanism' and taking a closer look at the sense of mechanism so common in contemporary biology.

By way of framing, consider a few of the more prominent ideas associated with the term 'mechanism'. Not all of these ideas are found in each historical period. Indeed, contemporary biologists and philosophers reject most of them. Nonetheless, a list helps to highlight some important similarities and differences among the diverse uses of the term 'mechanism' and to draw attention to the substantial differences between the meaning of the term in contemporary science and philosophy and in some of their ancestors.

(1) Mechanisms are **machines**. A machine is a contrivance, with organized parts whose interconnected workings can be easily understood. Mechanisms are often associated with machines because mechanisms are most conspicuous in human artifacts: the lever, the bellows, the mechanical clock, the water pump, the heat engine, the telegraph, and the computer. Each of these provides a model of intelligibility that has contributed to the diverse conceptions of the mechanisms in the natural world. Thinking about the natural world in terms of artifacts and engineering provides a more or less coherent set of commitments as to how to render the world intelligible and predictable, and as to how to bring it under human control. A different but related idea of machine is found in Archimedes and Galileo for whom the simple machines were mathematically describable in terms of equilibrium proportions. Arguably, this latter view, more than analogies to clocks, influenced subsequent physics (Peter Machamer, personal communication). T. S. Hall (1969) claims that the notion of mechanism as machine extends to different domains, such that macro-, meso-, and micromechanisms constitute, respectively, the solar system and whole cosmos as a machine, animal bodies as machines, and hidden microscopic machines producing observable (e.g., chemical and physiological) phenomena.

(2) Mechanisms are **naturalized**. That is, one need not appeal to occult objects or properties to explain their working. Occult objects and properties are ghosts in machines. Examples include Aristotelian forms and souls (vegetative and animal) as characterized by medieval Aristotelians and their Renaissance critics, as well as entelechies, homunculi, vital substances, and vital forces. What these share is that they are all entities, properties, or activities that resist explanation in terms of the basic principles allowed within a given mechanistic framework. From the perspective of such a framework, describing a mechanism for a phenomenon is a way of showing that nothing 'spooky' is required to explain it (cf. Sterelny & Griffiths, 1999). This denial of the vital and the occult in some cases provided a kind of unity of science, inextricably tying biology to the fundamental objects and properties in, for example, chemistry or physics. What counts as naturalized changes radically across different periods and different fields.

(3) Mechanisms are composed of a limited set of **basic principles** that are taken to be **intrinsically intelligible** and sometimes as **fundamental**. At different times and in different scientific fields, different basic principles have been accepted, and different kinds of properties have been construed as occult. For some Cartesian mechanists, mechanisms are composed of geometrical principles (extension and motion). For others, the basic principles include gravitational attraction, electromagnetic attraction and repulsion, and exchanges of conserved quantities, such as motion, momentum, and charge. Mechanism as a metaphysical doctrine is often associated with the view that everything can be understood in terms of these basic principles. As noted above, such understanding naturalizes a phenomenon by bringing it into line with the accepted principles of the mechanical science of the time. This notion of mechanism may also be closely aligned with the spirit of reductionism and the unity of science through reduction to fundamental mechanisms (cf. Sarkar, 1998; Schaffner, 1993). Others associate mechanism with multilevel explanations and a non-reductive view of science (see Craver, this issue).

(4) Mechanisms are **efficient** and **occurrent**. The parts of the mechanism, their activities, and their organization determine their behavior in the present. The behavior of the mechanism is influenced neither by the intentions of a creator (in the past) nor by the mechanism's goal or end-state (in the future). Mechanisms, in other words, are nonteleological. Nothing in this form of mechanism excludes the possibility that mechanisms have adapted parts or ends that arose via natural selection. Nonetheless, many believe that teleology can be naturalized via association with the operation of an adaptation generating mechanism (such as the mechanisms of natural selection and learning). Yet others believe that the notion of a mechanism is inherently teleological, because mechanisms are defined in part by what they do.

(5) Another assumption sometimes made is that mechanisms are **deterministic**. This means, roughly, that the state of a mechanism at one time is consistent with one and only one state for all future times. A similar set of commitments might be expressed by saying that mechanisms work according to universal and exceptionless laws of nature. Few contemporary physicists would endorse a

deterministic mechanical philosophy (because determinism is widely regarded as having failed in Newtonian mechanics, general relativity, and quantum mechanics), and few biologists can endorse an idea of mechanisms strongly associated with natural law (since laws are rare or nonexistent in biology). Indeed, most contemporary advocates of mechanical approaches to the philosophy of science explicitly allow for stochastic mechanisms (e.g., Bogen, this issue; Machamer, Darden, & Craver, 2000; Glennan, 1997; Woodward, 2002).

(6) Mechanisms are **atomistic**. In many historical periods, mechanism has been associated with the idea that all phenomena can ultimately be understood in terms of the activities of indivisible and impenetrable bodies. For example, the atomism of Democritus and Epicurus was later incorporated into the mechanical philosophy as portrayed by, for example, Pierre Gassendi (1592–1655) and Robert Boyle (1627–1691). Atomism, geometrical description, and contact action often occur together in formulations of the mechanical philosophy.

(7) Mechanisms are **temporally extended processes**. Many associate the term 'mechanism' with any process connecting a cause (or beginning state) to an effect (or end state). This sense leaves the properties of mechanisms quite underspecified and makes no commitment to a set of basic principles that compose mechanisms.

(8) Mechanisms can be exhaustively described in terms of **mathematical** relations among their component parts. Dijksterhuis (1961), for example, takes this mathematical view of mechanisms to be the central commitment of what he calls the 'mechanical world picture'. For many mechanists, the book of nature is written in the language of mathematics.

(9) Mechanisms may be explored through **experimentation**. The rise of the mechanical philosophy was closely associated with the rise of experimental science. The observable phenomena of the natural world are to be explained in terms of hidden mechanisms, and these mechanisms are to be inferred using well controlled experiments to sort how-actually from how-possibly descriptions of a mechanism. Westfall (1971), for example, shows that the mathematical characterization of phenomena, along with the development of machines for manipulating the world, allowed mechanical philosophers such as William Harvey (1578–1657) and Evangelista Torricelli (1608–1647) to subject mechanical hypotheses to rigorous test.

Philosophical attention to mechanisms, however, is not merely of historical interest. Many contemporary philosophers of science, and especially philosophers of biology, emphasize the importance of mechanisms. However, the view of mechanisms that they endorse shares few of the above commitments. Stuart Kauffman, for example, discusses 'articulation of parts' explanations in developmental biology. Articulation of parts explanations 'exhibit the manner in which parts and processes articulate together to cause the system to do some particular thing' (Kauffman, 1971, p. 257). William Wimsatt (1976) correctly notes that most biologists use the term 'reduction' to mean the discovery of mechanisms in precisely this sense. Kenneth Schaffner

(1993) concedes Wimsatt's point and claims that 'causal–mechanical' reductions are far more commonplace in biology and the biomedical sciences than are explanations fitting his classical reductive model of explanation. Looking more closely at the influence of the search for mechanisms on the practice of science, William Bechtel and Robert Richardson (1993) characterize the strategies of decomposition and localization, and they use those strategies to describe how mechanistic explanations are constructed and how mechanistic research programs progress and change over time. In more recent work prior to this issue, philosophers argue that appeal to mechanisms provides an account of causation (Salmon, 1984; Glennan, 1996; Machamer, Darden, & Craver 2000; Bogen, 2004), discovery (Craver & Darden, 2001; Darden, 2002; Thagard, 2003), explanation (Thagard, 1999; Machamer, Darden, & Craver, 2000; Glennan, 2002b; Woodward, 2002), functional analysis (Craver, 2001; Polger, 2004), interfield integration (Bechtel, 1986; Darden & Craver, 2002), and reduction (Sarkar, 1992). In light of this recent work and its historical connections, we believe that this issue, dedicated to the importance of mechanisms in biology, is timely.

2. Mechanism in historical context

The term 'mechanism' is best known for its association with a comprehensive view of both the natural world and the practice of science that had its apex in the seventeenth century. This view is most commonly associated with the works of Galileo Galilei (1564–1642), René Descartes (1596–1650), Thomas Hobbes (1588–1679), Christiaan Huygens (1629–1695), Pierre Gassendi, and Robert Boyle. Several historians of science, including Marie Boas (1952), Dennis Des Chene (2001), E. J. Dijksterhuis (1961), Pierre Duhem (1980 [1903]), Alan Gabbey (e.g., 1985, 1990), Daniel Garber, (e.g., 1992), Steven Shapin (1996), and Richard Westfall (1971), discuss the rise of the mechanical philosophy and its accompanying mechanical science in the sixteenth and seventeenth centuries. One emerging theme is that there is no single mechanical philosophy—that the notions of a mechanism and of mechanistic explanation have been expressed differently in different periods, accentuating different items from the above list. For some, the mechanical philosophy is associated primarily with atomism or other varieties of materialism. For some, its central feature is the rejection of teleology and the rejection of explanation via Aristotelian forms. For some, it is associated with mathematical description. For others, it is characterized in terms of explanations in terms of a few basic kinds of machines (e.g., Hero's simple machines) or activities (such as collision, attraction, or exchange of conserved quantities).

No name is more centrally associated with the mechanical philosophy than René Descartes (Westfall, 1971). Dennis Des Chene (2001) analyzes Descartes's mechanistic physiology in his *Spirits & clocks: Machine and organism in Descartes*. Descartes takes the intelligibility of machines for granted, and uses the model of a machine to supplant explanations in terms of Aristotelian forms. Descartes uses 'human-built machines, conceived *mechanistically*, to understand the actions of living bodies. The machine-model allows for the *transfer* to the living world, which at first is not [understood] mechanistically, of concepts that visibly do explain the actions of human-built machines' (ibid., p. 14). Des Chene shows how Descartes uses his mechanistic views to eliminate Aristotelian vegetative and animal souls from his physiology. Des Chene stresses that, for Descartes, mechanism is both a *method* and a *doctrine.* Mechanism as a *method*, 'says yes to some modes of explanation and no to others. It promotes an analysis of capacities . . . and discourages the invocation of irreducible powers' (ibid.). Mechanism as a *doctrine*, on the other hand, holds that, 'bodies have only those properties that follow upon their being extended substances, and perhaps a few additional properties like impenetrability. As a doctrine, it invites us to regard natural things, if complex, as combinations of extended substances interacting only by way of collision' (ibid.).

In his article in this issue, 'Mechanisms of life in the seventeenth century: Borelli, Perrault, Régis', Des Chene extends his analysis to post-Cartesian, seventeenth-century mechanisms of life in the work of G. A. Borelli (1608–1679), Claude Perrault (1613–1688), and P. A. Régis (1632–1707). These authors, writing a generation or two after Descartes, could accept mechanism as a method while rejecting the controversially restrictive ontology of mechanism as a doctrine. As a result, one finds in Borelli and Perrault a curious mixture of efforts to explain physiological phenomena in terms of machines and a continued place for non-mechanical factors in explaining the movements of animals. For example, although muscles can be understood as mechanisms, shifting forces among the parts of a machine, Borelli insists that such mechanisms presuppose force, and so do not explain its origins. Mechanism as a method does not preclude the existence of souls or non-mechanical powers. Nor does mechanism as a method require mechanism as an ontological doctrine for its value. That a comprehensive mechanistic natural philosophy was possible and desirable, as Descartes had argued, was no longer under dispute for these authors. This next generation got on with the business of finding mechanistic explanations in so far as they were possible. They argued about alternatives and possible limits without calling into question the utility or propriety of mechanism as a method.

The importance of mechanism in biology is not confined to the work of philosophers of the sixteenth and seventeenth centuries. Garland Allen discusses a different strand of mechanical philosophy in his, 'Mechanism, vitalism and organicism in late nineteenth and twentieth-century biology: The importance of historical context'. As his title suggests, Allen shares Des Chene's conviction that the term 'mechanism' should be treated with historical sensitivity. For Allen, the context is the late nineteenth to the mid-twentieth centuries in Europe and America, and the idea of mechanism plays out against the backdrop both of the institutionalization of biology and the industrialization of the modern world. Allen distinguishes between two senses of mechanism: philosophical *M*echanism, an atomistic materialist view of organic processes, and explanatory *m*echanism, the idea that explanations describe a set of interacting parts. Allen focuses primarily on philosophical Mechanism. He argues that Mechanism is intimately associated with the attempt to treat biology as a natural science, on par with physics or chemistry, and with the drive to bring the biological world under human control. Allen contrasts Wilhelm Roux's *Entwicklungsmechanik* with Hans Driesch's view that entelechies control embryonic development as a harmonious equipotential system. Elaborating Jacques Loeb's engineering ideal of controlling life phenomena via physico-chemical methods, Allen compares Loeb's work on artificial parthenogenesis with the more holistic approach to development offered by Hans Spemann. Allen argues that the Mechanistic view became a rallying point for early twentieth-century biologists. These experimentalists sought to professionalize aspects of biology that had previously been considered largely descriptive, including embryology, heredity, cytology, and evolution, by associating them with the search for mechanisms.

Des Chene's and Allen's articles suggest that there is considerable historical work to be done to understand how mechanical thinking entered the study of biology and how it has been expressed in different research programs and for different institutional ends. One common thread in these two articles is that each insists that mechanism and the mechanical philosophy should not be reduced to a few trite platitudes, such as the above list, but should be understood on their own terms and in their own historical contexts.

3. Mechanism in evolutionary biology

Whereas the preceding papers show that the ideas of mechanism and mechanistic explanation vary across historical contexts, it is also likely that they vary across scientific fields. A second set of three papers explores the importance of mechanisms and mechanistic explanation in evolutionary biology. While it is common to refer to 'mechanisms of evolution' or 'mechanisms of speciation', one might wonder if the term 'mechanism' means the same thing in discussions of evolution as it does in physics, chemistry, or physiology. Michael Ruse addresses this question historically, discussing Darwin's use of the term 'mechanism'. Jason Baker discusses various mechanisms of speciation considered from Darwin to the present. Finally, Rob Skipper and Roberta Millstein consider whether extant philosophical accounts of mechanisms and mechanistic explanation can make sense of the claim that natural selection is a mechanism for evolutionary change.

Michael Ruse, in 'Darwinism and mechanism: Metaphor in science', dissects the metaphor of nature as a machine. In one sense (see (1) above), the term 'mechanism' refers to a local contrivance, a device with parts designed or adapted to produce a function. In another, broader sense, the metaphor refers to the whole universe as machine designed by God (now a dead metaphor) or to a universe operating according to unbroken law (the sense described in (5) above). In the history of biology, the idea that the world is full of designed machines has been replaced by the idea that it contains evolved machines, built in a ramshackle way as evolution fashions them from available parts. Charles Darwin (1809–1882) uses the metaphor of contrivance as a heuristic to reason, via what is now called 'reverse engineering', from what an organism does to how its parts are adapted to work. Ruse enumerates several examples of Darwin's use of this metaphor, including his discussion of the mechanisms by which parts of orchids deposit pollen on visiting insects. However, somewhat surprisingly, Ruse's thorough search did not find Darwin calling natural selection a mechanism, in contrast to modern usage. Ruse argues for the heuristic importance of the metaphors of mechanism and machines in science and emphasizes (along with Allen) the historical contexts from which they emerge.

Jason Baker, in 'Adaptive speciation: The role of natural selection in mechanisms of geographic and non-geographic speciation', applies recent philosophical work on mechanisms to the analysis of speciation mechanisms. Among biologists, there is considerable controversy about whether speciation is an incidental by-product of geographical isolation or whether reproductive isolation can be, and often is, adaptive. *Prima facie*, it is difficult to see how it can be adaptive to reduce the number of one's potential mates in a population of organisms. Charles Darwin, Theodosius Dobzhansky, Ernst Mayr, and contemporary biologists offer different answers to this puzzle. Baker analyzes the diverse answers and disagreements by decomposing the speciation mechanisms described by the different authors into their component steps, and then showing clearly where the points of disagreement lie. Such mechanism decomposition allows precise localization of adaptive steps (if any). He argues that what is at stake in contemporary debates about speciation centers not merely on geographic isolation but on the adaptedness of isolating mechanisms.

Finally, Rob Skipper and Roberta Millstein, in 'Thinking about evolutionary mechanisms: Natural selection', explore whether extant philosophical analyses of mechanisms and mechanistic explanation adequately characterize the features of evolution by natural selection. Specifically, they consider Glennan's (1996, 2002a,b) interactionist view of mechanisms as systems and Machamer, Darden, and Craver's (2000) dualist view of mechanisms as organized entities and activities. Skipper and Millstein first develop a sophisticated representation of the processes and stages involved in natural selection. They then ask whether natural selection, so understood, fits the two target analyses of mechanisms. In particular, they argue that natural selection lacks the kinds of spatial organization required in the accounts of mechanisms. They also argue that the stochastic nature of evolutionary processes is ill fit to the appeals to regularity common to both accounts of mechanisms. Their conclusion is that more work is needed to accommodate the probabilistic causal relations found in natural selection. One might wonder whether the failure of fit suggests that natural selection is not a mechanism, or whether the account of mechanism should be broadened to allow for stochastic processes and other forms of organization, or whether there are different kinds of mechanisms in need of further analysis and comparison. Resolving this issue requires further debate among philosophers of evolutionary biology.

4. Mechanism and general issues in philosophy of science

Much of twentieth-century philosophy of science involves attempts either to reconstruct scientific arguments in the artificial language of logic or to reject that approach for science generally or for specific areas of science. One striking feature of recent work on mechanisms is that it has arisen somewhat independently of these disputes. It has developed not so much out of a reaction to Positivism or Post-

Positivism, but rather as the product of a thoroughly naturalistic approach to the history and philosophy of science. Mechanisms have struck so many philosophers as important for understanding biology because mechanisms are so important to many historical and contemporary biologists. This empirical fact leads one to wonder what traditional topics in the philosophy of science would look like if one were to start with mechanisms (rather than, for example, deductively closed axiomatic systems, set theoretic predicates, or universally quantified material conditionals) in thinking about, for example, causation, experimentation, explanation, reduction, and the unity of science. The next several papers address these issues from the perspective of mechanisms.

These more general issues in philosophy of science figure in the following papers: reduction (Darden, Craver), interfield integration (Darden, Craver), reasoning in discovery (Darden, Bechtel & Abrahamsen, Glennan), unification (Craver), evidence (Craver, Bechtel & Abrahamsen, Glennan), explanation (Bogen, Bechtel & Abrahamsen), the issue of generalizations (Darden, Bogen, Bechtel & Abrahamsen), causality (Bogen), mathematical idealizations (Bogen), and mechanistic models (Bechtel & Abrahamsen, Glennan). These authors stress the importance of mechanisms in such fields as Mendelian genetics, molecular biology, cell biology, neuroscience, cognitive science, and linguistics.

Lindley Darden, in 'Relations among fields: Mendelian, cytological and molecular mechanisms', criticizes previous philosophical accounts of the relations between Mendelian genetics and molecular biology. She argues for the view that the two fields investigate different, serially integrated hereditary mechanisms. The mechanisms of DNA replication, independent assortment of homologous chromosome pairs, segregation of homologous chromosomes, and gene expression operate at different times and have different working entities of different sizes. Cytology furnishes the mechanisms that produce the regularities captured in Mendel's laws. In contrast, discovery of molecular DNA mechanisms filled black boxes that were noted, but unilluminated, by Mendelian genetics. In showing that these different fields address different mechanisms, Darden develops a novel account of the relationship between Mendelian genetics and molecular biology and argues for its superiority over the alternatives that appear in this long-standing debate.

Carl Craver, in 'Beyond reduction: Mechanisms, multifield integration and the unity of neuroscience', advances a mechanistic model of the mosaic unity of neuroscience. Theories and explanations in neuroscience typically span multiple levels and draw on the findings from multiple fields. One notable example is a contemporary explanation of learning and memory that spans from the behaviors of organisms to the kinetics of molecules. Craver argues that the search for mechanisms serves as an abstract framework for integrating constraints supplied by different fields. This integration can occur at a given level, as researchers in different fields place different constraints on interacting components, and it can occur across levels, as the techniques of different fields are used to constrain interlevel relations. The unity of neuroscience that results is not a monolithic reduction of theories at one level to theories at the next, but rather a mosaic composed of constraints supplied by different fields on different aspects of a mechanism both at and between levels. Craver contrasts his view with reductive approaches to interfield integration and suggests that the mechanistic approach might have further implications for thinking about explanation and the metaphysics of levels.

Also making use of examples from neuroscience, Jim Bogen, in 'Regularities and causality; generalizations and causal explanations', contrasts two views of causality, which he designates 'Regularism' and 'Mechanism'. He argues for the Mechanistic account, which understands causation in terms of activities by which causes produce their effects, and against the Regularity view, which understands causation in terms of regularities as represented in actual or counterfactual generalizations. He argues that generalizations of these sorts are not required for explanations. If so, this raises the question of why scientists bother to construct generalizations in the first place. Bogen uses examples such as Alan Hodgkin and Andrew Huxley's simulation of the action potential to address this question. He notes that the generalizations in these equations are used to describe the facts to be explained, to suggest questions about causal mechanisms, to provide constraints on acceptable explanations, to measure or calculate crucial quantities, and to support inductive inferences that aid in successfully studying mechanisms and extending the application of mechanistic explanations from one case to others.

William Bechtel and Adele Abrahamsen, in 'Explanation: A mechanistic alternative', also address the role of generalizations in explanation. Using cognitive psychology as a resource—especially its findings on diagrammatic reasoning, simulation, and prototype theory—they contrast the Hempelian deductive–nomological view of explanation with their contemporary mechanistic account. On this account, explaining a phenomenon involves describing the mechanisms responsible for it, often by constructing a model that specifies key parts, operations, and organization and that can be run to simulate how their orchestrated function transforms certain parts or changes their properties. Using cell biology as a source of examples, they draw numerous contrasts between mechanistic and nomological explanations. Rather than linguistic expressions, representing mechanisms often involves diagrams or animations. Rather than logical deduction, making inferences about mechanisms often involves simulating the operation of the mechanism. Rather than dismissing the topic of discovery, it is possible to articulate procedures for discovering mechanisms, including decomposition and localization. Rather than merely testing predicted regularities, evaluating mechanistic explanations also involves investigating the operation and organization of the mechanism's components. Rather than adjusting the antecedents in a material conditional in order to generalize from a model system, scientists search for the similarities and differences between mechanisms operative in different circumstances. Like Bogen, Bechtel and Abrahamsen sharpen the contrast between mechanistic explanation and its alternatives and provide the foundation for a more focused discussion of what is distinctive about mechanistic explanation and how good mechanistic explanations are distinguished from bad.

Building on his interactionist account of mechanisms, Stuart Glennan, in 'Modeling mechanisms', provides an account of the nature and testing of mechanical models. A mechanical model, he claims, consists of both the *explanandum* and the *explanans*. That is, a mechanical model consists of a description of the mechanism's behavior and a description of the mechanism that accounts for that behavior. Using a case of two competing models of speech perception, Glennan examines a variety of strategies for model testing. A list of questions aids model evaluation by asking, for example, whether the model identifies all the components of the mechanism along with their causally relevant properties, and whether the model correctly represents the spatial and temporal organization of the mechanism. Different testing strategies include taking the mechanism apart and studying the behavior of the parts, as well as breaking the mechanism and examining its behavior under such non-standard conditions. The latter strategy, he argues, is especially useful for studying high-level cognitive mechanisms, which often have highly distributed parts and which cannot be dissected for ethical reasons. He concludes that models are not generally thrown out after failures of crucial experiments but are elaborated to gradually increase their degrees and respects of similarity to the mechanism being studied. Hence, model development, testing, and revision are intimately linked.

These papers show the rich diversity of views about mechanisms in biology. They provide a contrast between the views of mechanism in previous centuries and the use of mechanism in contemporary biology. New approaches to general questions in philosophy of science arise from these analyses of biological cases. These papers point to the rich resources yet to be exploited by further analysis of mechanisms in other fields of biology, as well as in other sciences, such as chemistry, meteorology, psychology, economics, and other social sciences.

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