Mechanisms in Science[1]

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0. Introduction

Many areas of science are animated by the search for mechanisms: experiments are designed to find them; explanations are built to reveal them; models are constructed to describe them; funding is disbursed to prioritize their discovery, and translational research is premised on their value for manipulation and control. Over the last twenty or thirty years, a number of philosophers of science, especially of the biological and neural sciences, have directed attention at the concept of mechanism. They have emphasized that mechanisms play central roles in discovery, explanation, experimentation, modeling, and reduction. At the same time, the idea of mechanism has for many served as a suggestive hint as to the metaphysics of the middle range: covering that domain of phenomena above the size scale of atomic physics and beneath that of planets, encompassing biology, physiology, psychology, and the human and so-called special sciences more generally. What must mechanisms be if they are to play these diverse roles? The phrase “The New Mechanism,” introduced to describe this research area, runs the risk of homogenizing what has become a heterogeneous body of work, serving many masters and tugging the analysis in many directions at once. Here, we attempt to collect some points of consensus while highlighting areas of productive disagreement and criticism going forward.

1. Central Articles and Books

Collected below is a list of central articles and books that have been of notable historical significance for understanding what the new mechanism sought to achieve and the diverse

[1] Thanks to Stuart Glennan and Lindley Darden for feedback on earlier drafts and to Sue McKinney for assistance formatting references.

areas of the philosophy of science in which it was thought to do useful service. Bechtel and Richardson's (1993) *Discovering Complexity* sketches a road-map (or decision-tree) that researchers face in the search for mechanisms. They focus specifically on the effort to decompose complex functions into subfunctions and to localize those subfunctions to different locations in a system, such as a cell or a body. These strategies, they point out, make sense against the background idea that the scientists aim, in their research, to discover mechanisms. Bechtel and Abrahamsen (2005) extend this work to offer a mechanistic theory of explanation opposed to the idea that explanations require knowing the laws of nature.

Glennan (1996) also deploys the concept of mechanism, but in the service of a philosophical analysis of causation. For Glennan (1996), mechanisms are the hidden connection Hume sought between a cause and its effect. Glennan has subsequently refined and revised his views in light of criticism and theory development See Glennan 2002 for contrasts with Salmon's mechanistic view. See Glennan 2017 for its latest development, emphasizing nominalism and an activities-based view of causation.

Machamer, Darden and Craver (2000; commonly known as MDC) were less concerned with a particular set of research strategies and with Hume's worries about causation than they were with the suggestion that attention to mechanisms could revolutionize the philosophy of science, transforming discussions of causation, discovery, functions, laws, levels, and reduction. They characterize mechanisms as entities and activities organized in the production of regular changes from start or set-up conditions to finish and termination conditions, and they argue how the drive to satisfy this explanatory demand shapes the practice of the biological and neural sciences. Following this publication, Darden pursued the issue of mechanism discovery, both alone and in cooperation with Craver and others. Key papers in this development are compiled in Darden (2006). Darden's view perhaps has its fullest development in Craver and Darden's 2013 *In Search of Mechanisms*. Craver, in contrast, began to work on the relevance of mechanism to the topic of scientific explanation. His most systematic treatment of the topic can be found in Craver (2007), which became a focus of much subsequent discussion.

Bechtel, W., & Abrahamsen, A. (2005). Explanation: A mechanist alternative. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, *36*(2 SPEC. ISS.), 421–441. http://doi.org/10.1016/j.shpsc.2005.03.010
Bechtel and Abrahamsen set the grounds for the epistemic interpretation of mechanisms as explanatory models. They discuss the benefits of this view over law-based accounts of explanation.

Bechtel, W. and Richardson, R. C. (1993). *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research*. Princeton: Princeton University Press.
Analyze the heuristics of decomposition and localization that is crucial for the discovery of mechanisms and in the development of mechanistic models in cell biology, cognitive neuroscience, and genetics.

Craver, C. F. (2007). *Explaining the Brain: Mechanisms and the Mosaic Unity of Neuroscience*. New York: Oxford University Press.

Discusses the nature of explanations in neuroscience and defends the view that good neuroscientific explanations are descriptions of multilevel mechanisms.

Craver, C. F., & Darden, L. (2013). *In Search of Mechanisms. Discoveries across the Life Sciences*. Chicago/London: University of Chicago Press.
Explains the relevance mechanism to discovery, with detailed examples and case-studies from the history of biology and contemporary biology, including the neural sciences. Details stages of mechanism discovery and strategies for solving specific discovery problems.

Darden, L. (2006). *Reasoning in Biological Discoveries: Essays on Mechanism, Interfield Relations, and Anomaly Resolution*. New York: Cambridge University Press.
Contains many of Lindley Darden's papers, alone and with co-authors, on how the search for mechanisms constrains scientific discovery, in addition to her earlier work on interfield theories and an anomaly-driven theory change.

Glennan, S. (1996) Mechanisms and the Nature of Causation. *Erkenntnis* 44: 49-71.
Proposes a mechanistic theory of causation according to which A and B causally interact only if there is a mechanism between them.

Glennan, S. (2002). Rethinking Mechanistic Explanation. *Philosophy of Science*, *69*(S3), S342–S353. http://doi.org/10.1086/341857
Develops his complex system view of mechanisms and contrasts it with Wesley Salmon's and Peter Railton's account.

Glennan, S. (2017). *The New Mechanical Philosophy*. Oxford University Press: Oxford.
See especially his discussion in Chapter 2 of the many ways of solving problems of both defining and demarcating mechanisms.

Machamer, P., Darden, L., & Craver, C. F. (2000). Thinking About Mechanisms. *Philosophy of Science*, *67*(1), 1–25.
This is the probably most prominent article of the new mechanistic literature. It provides starting points for many discussions such as how to characterize mechanisms, and how to describe the relationship between mechanisms and mechanistic explanation.

2. Overview Articles and Reference Works

These entries provide useful summaries or reviews of key topics in mechanistic philosophy of science. Each provides a useful, article-length entry into the literature.

Craver, C. F. and Darden, L. (2005). Mechanisms in Biology. Introduction. *Studies in the History of Biological and Biomedical Sciences*. 36: 233-44. doi:10.1016/j.shpsc.2005.03.001
Introduction to the refereed conference proceedings from the Reichenbach Conference at Washington University in St. Louis on Mechanisms and Mechanistic Explanation, along with invited articles. Compares contemporary mechanism to historical antecedents and discusses the problems of defining the construct precisely.

Craver, C. F. and Tabery, J. (2016). Mechanisms in Science. *Stanford Encyclopedia of Philosophy*, E N Zalta (ed.), Winter 16. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/win2016/entries/science-mechanisms/
The Stanford Encyclopedia article by Craver and Tabery provides an extensive overview of the new mechanistic philosophy covering the most central topics and open questions.

Glennan, S. (2015). Mechanisms and Mechanical Philosophy. In P. Humphreys (Ed.), *The Oxford Handbook of Philosophy of Science* (pp. 796–816). New York: Oxford University Press. doi:10.1093/oxfordhb/9780199368815.013.39
An overview of recent work on mechanism in the philosophy of science and metaphysics.

Glennan, S. and Illari, P. (2017). *The Routledge Handbook of Mechanisms and Mechanical Philosophy.* Routledge.
The handbook comprises over thirty chapters authored by many of the leading mechanist authors on the central topics of the research program, from its historical roots, to the nature of mechanisms, to their relevance for philosophy of science, and the applications of these ideas to special topics in various scientific disciplines.

3. Predecessors/Prehistory

The resurgence of interest in mechanisms around the turn of the new century developed out of and drew upon many different, more or less independent intellectual traditions. Mechanists were clearly inspired historically by the “mechanical philosophy” and its association with the rise of modern science. (see e.g., Boas 1952; Djiksterhuis 1961). Others found their muse in artificial intelligence, cognitive science, and engineering, specially the work of Herbert Simon 1962, who emphasized the import of near decomposability as a scientific heuristic, John Haugeland 1998, who followed Simon in exploring what it means to break a system at its joints, to William Wimsatt 1974, who explored the diverse ways one might decompose a system into its parts and called attention to important biases in the logical empiricists conception of theory reduction. All these thinkers emphasize in different ways the “nearly decomposable” structure of evolved systems: the idea that complex systems are themselves composed of more or less isolable components and that understanding such systems requires that we understand the behavior of the whole as produced through organized and interacting activities at multiple levels of organization. Stuart Kaufman 1974 argues that this feature of the organization of biological knowledge entails that the principle by which one carves biological material into working parts depends on a functional focus on something of interest the system is doing.

In the philosophy of science, mechanists drew especially upon criticisms of law-based views of scientific explanation, such as Carl Hempel’s covering-law model. Salmon 1984, for example, developed and catalogued numerous withering critiques against that model and proposed in its stead the thesis that scientific explanations work by showing how something is situated in the causal structure of the world. This work culminated in many ways in his classic Four Decades of Scientific *Explanation* (1989), which is required reading for anyone working on the topic of explanation, mechanistic or otherwise. Further impetus to the new mechanism came from other critics of covering-law model of explanation, who argued both for the absence of the required laws (Cartwright 1994; Brandon 1984) and for the importance of “production,” “nomological machines,” and “mechanisms” in our thinking about the natural world and the science that describes it.

These strands coalesced into a potent critique of the apparatus late 21st Century philosophers had inherited from logical empiricism. Every failing of traditional views seemed to demand that philosophy pay more attention to the mechanistic structure of the special sciences and beyond.

Boas, M. (1952). The Establishment of the Mechanical Philosophy. *Osiris*. *10*, 412-541. http://doi.org/10.1086/368562
A systematic and taxonomic overview of the main figures in the history of the mechanical philosophy and their diverse commitments in the Seventeenth and Eighteenth Centuries.

Brandon, R. N. (1984). Grene on Mechanism and Reductionism: More Than Just a Side Issue. *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association*, *2*, 345–353.
Expounds and expands Marjorie Grene's views about the centrality of mechanism in the philosophy of biology.

Cartwright, N. (1994). *Nature's Capacities and Their Measurement*. Oxford University Press. doi:10.1093/0198235070.001.0001
Criticizes the empiricist conception of laws and emphasizes instead the importance of capacities, underwritten by "nomological machines," in our understanding of natural regularities and scientific explanation.

Dijksterhuis, E.J. (1961). *The Mechanization of the World Picture*. New York: Oxford University Press.
Scholarly review of the main commitments of the mechanical philosophy from the ancient world through Newton. Argues that the mathematization of nature is the central feature of the mechanical philosophy.

Haugeland, J. (1998). *Having Thought.* Harvard University Press.
Collected essays in the philosophy of cognitive science and artificial intelligence with diverse insights into the structure of decompositional explanation, components, interfaces, boundaries, systems, and the cognitive and constructive nature of understanding.

Kauffman S.A. (1971). Articulation of Parts Explanation in Biology and the Rational Search for them. In: Buck R.C., Cohen R.S. (eds) PSA 1970. *Boston Studies in the Philosophy of Science*, vol 8. Springer, Dordrecht https://doi.org/10.1007/978-94-010-3142-4_18.
Describes explanation in developmental areas of biology as a search for understanding how parts articulate together in the service of some functional end. Kauffman emphasized the relativity of decomposition to a choice of a function that guides one's decompositional choices. This is a forerunner of the mechanistic thesis that there are no mechanisms simpliciter, only mechanisms of some phenomenon as selected by the experimenter.

Salmon, W. C. (1984). *Scientific Explanation and the Causal Structure of the World*. Princeton: Princeton University Press.
Argues against the covering-law model of explanation and in favor of a causal-mechanical view of explanation. Distinguishes "etiological" (backward-looking) from constitutive (inward-looking) explanations.

Salmon, Wesley C. (1989), "Four Decades of Scientific Explanation," in Philip Kitcher and Wesley Salmon (eds.), *Scientific Explanation. Minnesota Studies in the Philosophy of Science*, v. 13. Minneapolis, MN: University of Minnesota Press, pp. 3-219. (Also reprinted as a separate paperback.) Reviews forty years of philosophical discussion of the nature of scientific explanation, including arguments against the covering-law model and in favor of causal-mechanical approaches. Sets the backdrop for all subsequent discussions of mechanistic explanation.

Simon, H. (1969). *The Sciences of the Artificial.* Cambridge, MA: MIT Press.
Discusses how one builds explanations by identifying “nearly decomposable” components interacting across interfaces. Argues, through the parable of tempus and hora, that selective processes tend to generate systems that are nearly decomposable at multiple levels.

Wimsatt, W. (1974). Complexity and Organization in K. F. Schaffner and R. S. Cohen (eds.), PSA 1972, *Boston Studies in the Philosophy of Science, 20.* Dordrecht, Holland: Reidel, 67–86.
Among Wimsatt’s many articles in the 1970s that inspired early mechanistic writing on levels, organization, anti-reductionism, this is the article in which he explicitly claims that in many sciences, including biology, mechanism should replace reductionism as a regulative ideal on the search for explanations.

4. What are Mechanisms?

A central concern of early work on mechanisms has been to establish a non-trivial, yet sufficiently inclusive, characterization of the concept of mechanism. This task is complicated by several factors. First, both historically and in the present, the champions and detractors of mechanistic views emphasize different aspects of mechanisms: champions emphasizing the translational power of mechanism (Woodward 2002; detractors emphasizing machine-like simplicity of mechanistic approaches (Nicholson 2012) or the drive to biological reduction (Shapiro 2017). Second, the term “mechanism” is analyzed differently in the service of different philosophical projects, for example, in thinking about discovery, explanation, metaphysics, scientific integration (as emphasized by Andersen 2014 and Levy 2013). And finally, different philosophers start with different paradigm examples: where early discussions focused on cellular and molecular mechanisms by and large, philosophers of biology asked how the notion would fare in the context of evolutionary biology (Skipper and Millstein 2005). Can the concept be stretched so far without breaking? Likewise, Tabery’s 2009 work on mechanisms of heredity has helped the diverse forms of mechanistic explanation.

Three “characterizations” of mechanism coexisted for the first decade of the new-mechanism, and the effort to work out their differences called attention to the diverse problems any mechanical philosophy must struggle to solve (see also Machamer, Darden and Craver 2000 under *Central Articles and Books*; Bechtel and Abrahamsen 2005; Glennan 1996). The subtle differences among them defy simple summary. Very useful discussions of this can be found in Illari and Williamson 2012 and Glennan 2017, in addition to Andersen 2014 and Levy 2013. A fourth dominant perspective has increasingly gained ascendency, melding Woodward’s 2002 interventionist model of explanation with mechanistic explications of the organization of mechanisms, particularly their structure across multiple levels of organization.

Some object that the term “mechanism” has been weakened to the point where it has no substantive content (e.g., Shapiro 2017). Yet, even a minimal notion of mechanism (as favored by e.g., Illari and Williamson 2012; and Glennan 2017) would appear to admit some uncontested contrast classes.

Anderson, H. A (2014) Field Guide to Mechanisms: Parts I and II *Philosophy Compass* 49: 274-293. https://doi.org/10.1111/phc3.12119

Distinguishes five senses of mechanism in the philosophy of science and their diverse commitments and theoretical contexts.

Glennan, S. (2017). *The New Mechanical Philosophy*. Oxford University Press: Oxford. See especially his discussion in Chapter 2 of the many ways of solving problems of both defining and demarcating mechanisms.

Illari, PMK and Williamson, J. (2012). What is a mechanism? Thinking about mechanisms across the sciences. *European Journal for Philosophy of Science* 2(1), 119-135. An exceptionally fruitful review of the difficulties formulating a workable definition of “mechanism.” Proposed a consensus characterization of mechanism a decade after the MDC formulation, that sorted and clarified the commitments a mechanist ought to undertake concerning the nature of mechanisms.

Levy, A. (2013). Three Kinds of New Mechanism. *Biology & Philosophy 28*(1), 99-114. Distinguishes three different ways of characterizing mechanism depending on whether one seeks a philosophical theory of causation, discovery, or of scientific methodology. Argues that failure to distinguish these leads to confusion over whether natural selection is a mechanism.

Nicholson, D. J. (2012). The Concept of Mechanism in Biology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences 43*(1), 152–163. http://doi.org/10.1016/j.shpsc.2011.05.014
Argues that there are three distinct meanings of the concept mechanism that have to be kept apart: a philosophical thesis about the nature of life and biology, the internal workings of a machine-like structure, or the causal explanation of a particular phenomenon, where only the latter is crucial for the analysis of the life sciences.

Shapiro, L. (2017). Mechanism or Bust? Explanation in Psychology. *British Journal for the Philosophy of Science. 68*(4), 1037-1059. https://doi.org/10.1093/bjps/axv062
Argues, as part of a defense of functionalism that the thesis that psychology must adhere to mechanistic explanatory ideals is either empty or false.

Skipper, Robert A., Jr. and Roberta L. Millstein (2005), "Thinking about Evolutionary Mechanisms: Natural Selection," in Carl F. Craver and Lindley Darden (eds.), Special Issue: "Mechanisms in Biology," *Studies in History and Philosophy of Biological and Biomedical Sciences* 36: 327-347.https://doi.org/10.1016/j.shpsc.2005.03.006**.** Explores whether natural selection is a mechanism by asking whether the key features of the MDC characterization indeed apply to natural selection.

Tabery, James G. (2004), "Synthesizing Activities and Interactions in the Concept of a Mechanism," *Philosophy of Science* 71: 1-15. Argues that the concept of mechanism requires both activities and interactions in order to accommodate mechanisms that explain differences in a population.

Woodward, J. (2002). What Is a Mechanism? A Counterfactual Account. *Philosophy of Science*, *69*(S3), S366–S377. http://doi.org/10.1086/341859
Woodward develops a counterfactual account of mechanisms in terms of interventions, invariance, and modularity.

5. Discovery and Evidence

Bechtel and Richardson 1993 developed a notion of mechanistic explanation as one piece of a project to understand the strategies guiding progress in contemporary biological and neural science. They emphasized the importance of characterizing the phenomenon and describe the process by which the phenomenon is often transfigured as scientists attempt to localize and decompose the mechanism in question. Following in this tradition, Thagard 1999 used probabilistic models of causal reasoning to inform the process by which medical scientists revised their explanation for stomach ulcers.

Building on decades of research on interfield integrations in Mendelian genetics, Lindley Darden 2006 found the concept of a mechanism a useful starting point for identifying and describing diverse strategies scientists use in the search for mechanisms. She conceptualizes mechanism discovery as a search through a multidimensional space of possible mechanisms. An evidential *constraint* on the space of possible mechanisms is a finding that shifts credence across that space. Constraints include facts about entities, activities, and features of their spatial, temporal, hierarchical, and causal organization. Progress in that search involves trading sketches for complete descriptions (filling in black boxes) and trading how possibly for how-actually-enough descriptions for the purposes at hand. Craver and Darden 2013 provide a useful summary of mechanistic perspectives on discovery.

A number of philosophers have argued that attention to the mechanistic structure of biological explanations helps to illuminate how scientists resolve specific evidential questions, such as how to infer from model organisms (Steel 2008; Howick et al. 2013), how to learn about mechanisms by building robots, and how to devise types of experiments to answer specific questions in mechanism discovery (Craver and Darden 2013). In a recent paper, Darden et al. 2018 use the MDC conception of a mechanism as the basis for a database for storing published information about disease mechanisms that might be taegeted in translation.

In the context of medicine, the term “mechanism” is essential in debates over different strata of evidence in the hierarchy of evidence-based medicine, where knowledge of mechanisms is often accorded very low epistemic priority. Philosophers ask about the epistemic value of knowing the mechanism between cause and effect. According to the Russo-Williamson thesis, for example, to establish that A causes B, one must know that B depends statistically on A and, in addition, know the mechanism by which A causes B (Williamson and Russo 2007; see also Illari 2011; and Clark et al. 2014). In the context of medical ethics, Kennedy and Malanowski (2019) argue that knowledge of the mechanisms of drug action can often inform important decisions in the clinical encounter and in patients lives.

Clarke, B. Gillies, D., Illari, P., Russo, F., Williamson, J. (2014). Mechanisms and the evidence hierarchy. *Topoi*. *33*(2), 339-360.
Argues contrary to the evidence-based-medicine hierarchy that knowledge of mechanisms plays a complementary role in establishing causation to evidence from controlled clinical trials.

Craver, C. F., & Darden, L. (2013). *In Search of Mechanisms. Discoveries across the Life Sciences*. Chicago/London: University of Chicago Press.
An encyclopedic but readable review of the mechanistic writings on discovery framed by both prominent and novel examples of mechanism discovery from the history of the biological sciences.

Darden, L. (2006). *Reasoning in Biological Discoveries: Mechanism, Interfield Relations, and Anomaly Resolution*, New York: Cambridge University Press.
Contains all of Darden's major papers on the discovery of mechanisms, including classic early works with Machamer and Craver.

Darden, Lindley, Kunal Kundu, Lipika R. Pal, and John Moult (2018), "Harnessing Formal Concepts of Biological Mechanism to Analyze Human Disease," *PLoS Computational Biology* 14 (12): e1006540.
https://doi.org/10.1371/journal.pcbi.1006540

Uses the MDC characterization of mechanisms as the basis for a computational database for storing knowledge of disease mechanisms.

Datteri, E. and Tamburrini, G. (2007). Biorobotic Experiments for the Discovery of Biological Mechanisms. *Philosophy of Science*. *74*(3), 409–430.
https://doi.org/10.1086/522095
Discusses the use of robotic experiments to test biological mechanisms, including the use of strategies to map robotic systems to their biological targets and calibrating the model to the world.

Howick, J., Glasziou, P. and Aronson J.K. (2013). Problems with Using Mechanisms to Solve the Problem of Extrapolation. *Theoretical Medicine and Bioethics*, *34*(4), 275–291.
Critical but nonetheless optimistic discussion of Steel's 2008 account of mechanistic extrapolation, showing the challenges any account of mechanistic extrapolation must face and showing how, once faced, mechanistic approaches aid in the extrapolation of medical knowledge from models to targets.

Kennedy, Ashley and Sarah Malanowski, (2019), "Mechanistic Reasoning and Informed Consent," *Bioethics* 33(1): 162-168. https://doi.org/10.1111/bioe.12500
Discusses the relevance of knowing the mechanism of action of a drug to patients for to scaffold decision-making for a wide range of clinical situations.

Steel, D.P. (2008). ***Across the Boundaries: Extrapolation in Biology and Social Science*, New York: Oxford University Press.**
Offers a mathematical representation of the concept of mechanism suited for probabilistic reasoning about how mechanisms are organized. Then uses this model to discuss strategies for extrapolating from one species to another.

Thagard, P. (1999). ***How Scientists Explain Disease*. Princeton, NJ: Princeton University Press.**
Uses philosophical theories of causation to develop a theory of discovery in biomedicine based on the discovery of *H. pylori* bacteria as a cause of ulcers. Thagard emphasizes psychological, material (e.g., instruments), and social factors influencing growth of mechanistic knowledge.

Williamson, J. and Russo, F. (2007). Interpreting Causality in the Health Sciences. ***International Studies in the Philosophy of Science*. *21*(2), 157-170.**
Defends an epistemic view of causation according to which causation is established on the basis of both knowledge about physical mechanisms and about probabilistic relationships. The epistemic view unifies these two aspects of mechanistic knowledge in a single theory of causation.

6. Mechanisms, Reduction and Interfield Integration

The term ‘reduction’ sometimes is used to refer to a general *explanatory orientation*, i.e., a commitment to explain wholes in terms of their parts (Kaiser 2015), and other times to describe a particular model of such explanations, i.e., the covering-law explanation of higher-level laws via deductive subsumption under lower-level laws and boundary conditions. Mechanists tend to embrace downward looking explanatory orientation as one important way of viewing the causal structure of the world (along with etiological and contextual orientations). But they have tended to deny that the covering-law model captures its core, causal features of such explanations. Such models have well known challenges distinguishing causal from non-causal laws and so fail to capture key norms governing interlevel explanations (see Craver and Povich 2013 and *Mechanisms and Explanation*).

Mechanists tend to emphasize the hierarchical organization of mechanisms (see also *Levels of Mechanisms and Interlevel Causation*), in which mechanisms are constituted by components organized and interacting with one another, which components are themselves mechanisms composed of organized components, and so on. The task of the mechanistic scientist is to learn how the various parts, at various levels of organization, work together so that some phenomenon occurs. The fact that science aims at filling out such abstract structures (mechanisms within mechanisms bridging levels of organization and different scientific perspectives) provides a common focus for otherwise diverse fields, practices, and techniques.

Different fields integrate their results when they contribute constraints on the same mechanism (Bechtel 2007; Darden 2006). Scientists working in different fields and traditions, using different instruments and speaking different languages, can unify their results by placing meaningful constraints on the space of plausible mechanisms for a given phenomenon (Craver and Darden 2013). They are integrated in collaborative discovery of a mechanism (Fagan 2016). Such forms of scientific integration might occur across levels (the province of the classical reduction model) or within levels (which the reduction model is not equipped to describe).

The metaphysical demands of this multilevel perspective remain to be settled, and different philosophers attach different metaphysics to these same descriptive facts. Krickel 2018 argues for an ontological anti-reductionism based on the fact that phenomena are behaving systems that contain their mechanisms. Fazekas and Kertész 2011 offer a reductionist metaphysics for mechanisms that attempts to make sense of levels and interlevel experiments in an otherwise flat world. Sullivan 2009 finds that even this permissive notion of integration demands more than the methodological disunity of neuroscience can now, or perhaps ever, supply.

Bechtel, W. (2007). Reducing Psychology while Maintaining its Autonomy via Mechanistic Explanations. In M. Schouten & H. L. De Joong (Eds.), *The matter of the mind: philosophical essays on psychology, neuroscience and reduction.* pp. 172–198. Oxford: Basil Blackwell.
Bechtel highlights how the relevance of organization within mechanisms is incompatible with a purely reductionist picture of explanation.

Craver, C. F., & Darden, L. (2013). *In Search of Mechanisms. Discoveries across the Life Sciences*. Chicago/London: University of Chicago Press.
In Chapter 10, they describe interfield integration as the coalescence of findings from different fields onto an abstract description of a mechanism. They contrast their view with reductive models and discuss it as a kind of unity achieved across many areas of science.

Craver, C.F. and Povich, M. (2017). Mechanistic Levels, Reduction, and Emergence. S. Glennan and P. Illari, (eds.), Routledge Handbook of Mechanisms and Mechanical Philosophy. New York: Routledge. pp. 185-205.
Discusses the mechanistic view of levels and reviews the mechanistic reasons for rejecting reductionism as an explanatory thesis. Also contains discussions of interlevel causation and the compatibility of manipulationism and interlevel experiments.

Darden, L. (2006) *Reasoning in Biological Discoveries: Mechanism, Interfield Relations, and Anomaly Resolution*, New York: Cambridge University Press.
Explores forms of and strategies for building interfield theories to describe mechanisms. Contains many of Darden's classic articles, with and without coauthors.

Fagan, M. B. (2012). The Joint Account of Mechanistic Explanation. *Philosophy of Science 79*(4), 448–472. https://doi.org/10.1086/668006
Emphasizes the idea that mechanistic explanation, and interfield integration, require an appropriate fit between parts, on the one hand, and researchers, on the other.

Fazekas, P., & Kertész, G. (2011). Causation at different levels: tracking the commitments of mechanistic explanations. *Biology & Philosophy*, *26*(3), 365–383. http://doi.org/10.1007/s10539-011-9247-5

Argues that the mechanistic approach is committed to ontological, explanatory, and integrational reductionism given that, in order for a mechanism to constitute a phenomenon, the mechanism as a whole must do the very same thing as its organized parts. As a consequence, the mechanistic approach is committed to identity statements and bridge principles connecting the different causal terms used by different scientific disciplines.

Kaiser, M. I. (2015). ***Reductive Explanation in the Biological Sciences*****. Springer International Publishing. Retrieved from** **https://books.google.de/books?id=hDA3CwAAQBAJ**
Develops a descriptively adequate account of reductive explanation and contrasts it with non-reductive explanation.

Krickel, B. (2018). ***The Mechanical World - The Metaphysical Commitments of the New Mechanistic Approach*****. Springer.**
Argues for ontological and explanatory anti-reductionism with regard to higher-level mechanistic phenomena based on the argument that higher-level phenomena are behaviors of objects/systems that with spatiotemporal extensions beyond the mechanisms responsible for the behavior.

Sullivan, J. (2009). The Multiplicity of Experimental Protocols: A Challenge to Reductionist and Non-Reductionist Models of the Unity of Neuroscience. ***Synthese*****,** ***167*****(3), 511–539. https://doi.org/10.1007/s11229-008-9389-4**
Argues that the debate about reductionism cannot be settled yet as philosophers have failed to pay sufficient attention to the fact that experimental practice deals with a multiplicity of experimental protocols.

7. Mechanistic Explanation (General Background)

Mechanistic explanation involves showing how something is situated in the causal structure of the world. Etiological explanations show how an event came about by revealing its antecedent causes. Constitutive explanations explain some event or type of event by decomposing it into component parts and showing how they work together in the production of the phenomenon to be explained. Contextual explanations are oriented toward the role of the item in a causal context (Bechtel 2009). Mechanists have made considerable progress in understanding the constitutive form of causal-mechanical explanation (see Craver 2007; Glennan 2002).

Both Cummins 2000 and Craver 2007 rehearse the well-known and apparently undermining anomalous “counter-examples” to the covering-law model: its inability to distinguish correlation from causation (barometers and storms), relevant from irrelevant factors (birth control pills and male pregnancy), the asymmetrical power of causes to explain their effects (flagpoles and shadows). Derivational models of reduction, mechanists argued, face analogous challenges (including the fact that a conjunct follows from any conjunction, regardless of whether both conjuncts are explanastorily relevant). The core epistemic commitment of the covering-law model, that explanations must show that the phenomenon was to be expected, failed in cases when the irreducibly improbable happens.

Although mechanists univocally reject the covering-law model, they do so for different reasons. Some object to the covering-law model’s insistence on laws, which rules out the existence of explanations in sciences where there are no laws (Bechtel and Abrahamsen

2005; Cummins 2001). Some object to the idea that explanations must be represented as arguments, and so in propositional form, as apparently required by the covering-law model (Bechtel and Abrahamson 2005). Still others object, as above, that the argumentative and nomological structure of the covering-law model fails to respect the causal structure of our explanations. These philosophers (e.g., Glennan 2002; Craver 2014) emphasize the appropriate referents of explanatory models, i.e., the *ontic* structures to which they must point to count as explanatory over the specific representational form the models take. Consistent with this view, Hochstein 2017 argues that even relatively simple explanations typically require appeal to multiple models and diverse background information to determine when models do and do not apply. Explanations and models are not individuated by the same criteria. For objections to this ontic perspective and reflections on this discussion, see Bokulich 2016, Wright 2012, and Illari 2013. Readers should beware of the confusion that results from failing to mark when authors are speaking in an ontic versus representational mode.

Bechtel, W. and Abrahamsen, A. (2005). Explanation: A Mechanistic Alternative. *Studies in the History and Philosophy of the Biological and Biomedical Sciences*. *36*, 421 – 441.
Develop an explicitly representationalist theory of mechanistic explanation and contrast it with the covering-law explanation by appeal to the latter's reliance on laws of nature found lacking in biology and cognitive science.

Bechtel, W. (2009). Looking down, around, and up: Mechanistic explanation in psychology. *Philosophical Psychology*, *22*(5), 543–564.
http://doi.org/10.1080/09515080903238948
Emphasizes diverse ways of situating an item in the hierarchically organized causal structure of the world.

Bokulich, A. (2016). Fiction as a vehicle for truth: Moving beyond the ontic conception. *The Monist*. *99*(3), 260-279. Argues that idealization, the deliberate use of false models to explain, runs counter to the ontic conception of explanation. Idealization is also taken to be problematic for the covering-law model.

Craver, C. F. (2007). *Explaining the Brain: Mechanisms and the Mosaic Unity of Neuroscience.* New York: Oxford University Press.
Articulates and defends a theory of mechanistic explanation in the neuroscience. Synthesizing mechanistic considerations of organization and multilevel organization with manipulationist theories of causation, Craver develops a philosophy of science made to accommodate multilevel mechanistic sciences.

Craver, C. F. (2014). The Ontic Account of Scientific Explanation. In M. I. Kaiser, O. R. Scholz, D. Plenge, & A. Hüttemann (Eds.), *Explanation in the Special Sciences: The Case of Biology and History* pp. 27–52. Dordrecht: Springer Netherlands.
http://doi.org/10.1007/978-94-007-7563-3_2
Following Salmon (1984), distinguishes ontic, cognitive, epistemic and pragmatic views of explanation and argues that ontic commitments are fundamental for any philosophical theory of explanation: For any philosophical theory, there is a fundamental decision to be made

about which sorts of worldly structure any legitimate explanation must describe if it is to get the explanation right.

Cummins, R. (2000). How Does It Work? Vs. What Are The Laws? Two Conceptions of Psychological Explanation. in F. Keil and R. Wilson (Eds.), Explanation and Cognition. Cambridge, MA: MIT Press, pp. 117–145.
Argues against the covering-law model of explanation and in favor of thinking of explanation in psychology as involving decomposition into component functions arranged so as to exhibit the effect in question.

Glennan (2002). Rethinking Mechanistic Explanation. *Philosophy of Science*. *69*(53), 342-353.
Contrasts Salmon's physical account of mechanisms with his own "causal systems" account. Considers how Woodward's interventionist theory fits with emerging interest in mechanistic explanation.

Hochstein, E. (2017). Why one model is never enough: a defense of explanatory holism. *Biology & Philosophy*, *32*(6), 1105–1125. http://doi.org/10.1007/s10539-017-9595-x
Argues that typically, explanations of any complexity require multiple models to fully express their content. This attacks the close association between models and mechanisms and suggests that we should expect that for any mechanism, we should expect many models.

Illari, P. M. (2013). Mechanistic Explanation: Integrating the Ontic and Epistemic. *Erkenntnis*, *78*(SUPPL.2), 237–255. http://doi.org/10.1007/s10670-013-9511-y
Seeks to integrate ontic and epistemic approaches, in part by pointing out that contemporary uses of the term "epistemic" diverge from its historic usage. While the historic uses refer to the inferential, argument-centered nature of covering-law explanations, nowadays "epistemic" is simply used to mean "representational".

Wright, C. D. (2012). Mechanistic explanation without the ontic conception. *European Journal for Philosophy of Science*, *2*(3), 375–394. http://doi.org/10.1007/s13194-012-0048-8
Argues that the ontic conception of explanation rests on a category mistake, according to which the world is said to explain itself to itself. All explanations must be representational: provide information about something to someone.

8. Mechanistic and Causation

An important fault-line among defenders of the new mechanisms concerns how one thinks about causality. Some, including Machamer et. al 2000 and Bogen 2008, emphasize the importance of production to our thinking about causation. What matters in explanation is seeing how the effect is produced through a series of causes, understood as concrete activities such as bumping, burning, and attracting (see also Waskan 2011; for a recent example, see Glennan 2017; Illari and Williamson 2013; Krickel 2018). Others, such as Woodward 2001; 2011 and following him, Craver 2007 and Menzies 2012 have tended to emphasize (in addition) relationships of difference-making as fundamental to our notion of causal, and so explanatory, relevance. (Glennan 2017 attempts to integrate these two approaches).

This approach has not been without critics. For example, Cartwright 2017 argues that interventionism, and the structural equation modeling that comes with it, rely on assumptions (such as modularity of causes) that are violated in even moderately complex systems. See Kourikoski 2012 for an exploration of what does and does not count as a counter-example to the formal notions of modularity at stake. See Menzies 2012 for arguments in favor of requiring a modularity requirement on any adequate theory of mechanisms.

Glennan 1996 offers a different view of causation entirely, according to which one event causes another if and only if the two events are linked by a mechanism. This account has been charged with circularity, though Glennan argues the circularity is not vicious, a dubious virtue shared by many theories of causation. In 2017, his view now embraces both activities and difference making as essential components of mechanistic explanation.

Bogen, J. (2008). Causally Productive Activities. Studies in History and Philosophy of Science Part A 39:112-123.

Defends a singularist, activity-based view of causation tracing to Anscombe according to which the term “cause” is generic and caries no content beyond that carried by terms for specific activities (e.g., magnetic attraction or neurotransmitter release).

Cartwright, N. (2017). Can Structural Equations Explain How Mechanisms Explain? In H. Beebee, C. Hitchcock, & H. Price (Eds.), *Making a difference : Essays on the Philosophy of Causation* pp. 132–152. Oxford: Oxford University Press. Retrieved from http://dro.dur.ac.uk/19816/1/19816.pdf?DDD24+cmdm84+d700tmt+dul4eg

Argues, contra Craver 2007 and Menzies, that interventionism, and the structural equation models that come with it, is inadequate to capture the nature of explanation in many areas of science. Emphasizes the ontic structure of nomological machines.

Glennan, S. (1996). Mechanisms and the Nature of Causation. *Erkenntnis*, *44*(1), 49–71. http://doi.org/10.1007/BF00172853

This is Glennan’s first paper presenting his theory of causation in terms of mechanisms.

Illari, P. M., & Williamson, J. (2013). In Defense of Activities. *Journal for General Philosophy of Science*, *44*(1), 69–83. http://doi.org/10.1007/s10838-013-9217-5

Defend an activity-based analysis of mechanisms and provide an account of what activities are.

Krickel, B. (2018). *The Mechanical World - The Metaphysical Commitments of the New Mechanistic Approach* (Vol. 13). Cham: Springer International Publishing. doi:10.1007/978-3-030-03629-4

Krickel develops a singularist, activity-based account of causation.

Kuorikoski, J. (2012). Mechanisms, Modularity and Constitutive Explanation. *Erkenntnis*, *77*(3), 361–380. http://doi.org/10.1007/s10670-012-9389-0

Argues that the modularity assumption presumed by many interventionist accounts of mechanisms is not threatened by the existence of systems with feedback and complex organization.

Menzies, P. (2012). The Causal Structure of Mechanisms. *Studies in the History and Philosohy of Biology and Biomedical Sciences. 43*(4), 796-805. https://doi.org.10.106/j.shpsc.2012.05.008
Argues in favor of an interventionist theory of mechanistic explanation and makes explicit how details of manipulationism might be used to improve the treatment in Craver 2007, with particular attention to the modularity of components in mechanistic explanations.

Psillos, S., (2004). A Glimpse of the Secret Connexion: Harmonizing Mechanism with Counterfactuals. *Perspectives on Science*, *12*(3), 288–319. https://doi.org/10.1162/1063614042795426
Compares the mechanistic account of causation with the interventionist account of causation and argues that the latter is more basic than the former.

Waskan, J. (2011). Mechanistic explanation at the limit. *Synthese*, *183*(3), 389–408. http://doi.org/10.1007/s11229-010-9869-1
Argues against the assimilation of mechanistic explanation to Woodwardian interventionism (at risk of rendering mechanistic explanation merely one form of a more general kind of explanation) and defends an actualist causal theory of explanation as an alternative.

Woodward, J. (2011) Mechanisms revisited. *Synthese* 183:409-427. http://doi.org/10.1007/s11229-011-9870-3
Defends an interventionist, difference-making theory of mechanisms in contrast to Waskan's proposals. Clarifies the commitments of the interventionist approach.

9. Mechanisms and Laws of Nature

Some of the earliest expositors of the new mechanistic philosophy emphasized a contrast between law-based and mechanisms-based philosophy of science (Machamer, Darden and Craver 2000; Bechtel and Abrahamsen 2005, see *Central Books and Overviews*). They often target a logical empiricist conception of laws in their attacks. Leuridan (2010) argued that mechanisms cannot replace laws of nature in our thinking about type- or even token-level explanations; indeed, there can be no science worthy of the name without laws. Kaiser and Craver (2013) argue that mechanists do not deny the importance of generalization for biology but rather emphasize knowledge of causal structures, specifically. As they point out, the problem with the covering-law model is not its emphasis on generality but its failure to distinguish causal laws from non-causal (and so often non-explanatory) generalizations. Furthermore, as Cummins (2000) argued, law-like generalizations are often the explananda of mechanistic explanation. Given that scientific explanation is essentially concerned with explaining types of phenomena (e.g., the action potential in general vs. a specific occurrence of it) true generalizations concerning mechanisms are crucial for scientific explanation as well (Andersen 2011, 2012; Bogen 2005; Krickel 2018). Nonetheless, some mechanists argue that causation is fundamentally a local and singular matter: whether a pushes b is a matter settled by a and b irrespective of whether A-type things tend to push B-type things (see Illari and Williamson 2011 and Glennan 2010). DesAutels (2011) and Krickel (2018) develop an idea of mechanism that allows explicitly for stochastic processes.

Andersen, H. (2011). Mechanisms, Laws, and Regularities. *Philosophy of Science, 78*(2), 325–331. http://doi.org/10.1086/659229

In this article, Holly Andersen clarifies the relation between laws, mechanisms, and regularities. She argues that mechanisms are alternative analytic tools to laws as both attempt to explain regularities.

Andersen, H. (2012) The Case for Regularity in Mechanistic Causal Explanation. *Synthese*, *189*(3), 415–432. https://doi.org/10.1007/s11229-011-9965-x
Andersen defends a regularity-based characterization of mechanisms that rests on a taxonomy of kinds of regularity.

Bogen, J. (2005). Regularities and Causality; Generalizations and Causal Explanations, in C. F. Craver and L. Darden (eds.), Mechanisms in Biology. *Studies in History and Philosophy of Biological and Biomedical Sciences.* 36(2), 397–420. https://doi.org/10.1016/j.shpsc.2005.03.009
Argues that generalizations are not crucial for causal explanation but rather mechanisms that are often irregular.

Cummins, R. (2000). ''How Does It Work? Vs. What Are The Laws? Two Conceptions of Psychological Explanation,'' in F. Keil and R. Wilson (eds.), Explanation and Cognition. Cambridge, MA: MIT Press, 117–145.
Argues against the covering-law model of explanation and in favor of thinking of explanation in psychology as involving decomposition into component functions arranged so as to exhibit the effect in question.

DesAutels, L. (2011) Against Regular and Irregular Characterizations of Mechanisms. *Philosophy of Science*, *78*(5), 914–925. https://doi.org/10.1086/662558
Argues for a stochastic characterization of mechanisms.

Glennan, S. (2010). Ephemeral Mechanisms and Historical Explanation. *Erkenntnis*. *72*(2), 251–266. http://doi.org/10.1007/s10670-009-9203-9
Glennan argues that even historical explanations of singular events can be mechanistically explained in terms of what he calls "ephemeral mechanisms."

Illari, P.M. & Williamson, J. (2011). Mechanisms Are Real and Local. In P. M. Illari, F. Russo & J. Williamson (eds.), Causality in the Sciences. OUP Oxford. http://doi.org/10.1093/acprof:oso/9780199574131.003.0038
Illari and Williamson argue that for token-level mechanistic explanations, generalizations about the phenomenon-to-be-explained are irrelevant.

Kaiser, M. and Craver, C.F. (2013). Mechanisms and Laws: Clarifying the Debate in H-K. Chao, S-T. Chen and R. L. Millstein, (eds.) Mechanism and Causality in Biology and Economics, Springer. https://doi.org/10.1007/978-94-007-2454-9_7
Responds to Leuridan's paper on the role of laws in mechanistic explanations and argues that the law based view Leuridan favors cannot, without stipulation, explicate the norms of explanation. An important corrective to any writing on mechanisms and laws.

Krickel, B. (2018). A Regularist Approach to Mechanistic Type-Level Explanation. *British Journal for the Philosophy of Science 69*(4), 1123–1153. http://doi.org/10.1093/bjps/axx01

Considers how to explicate the idea of type-level mechanistic explanations. What does it mean for a mechanism to be regular? Defends the “reverse regularity” thesis.

Leuridan, B. (2010). Can Mechanisms Really Replace Laws of Nature? *Philosophy of Science*, *77*(3), 317–340. https://doi.org/10.1086/652959
Compares the mechanistic account of explanation with Mitchell's pragmatic notion of laws and argues that mechanisms do not provide an alternative to laws of nature.

10. Mechanisms and Natural Kinds

A common taxonomic principle among sciences dealing with complex and higher-level phenomena is to carve the world at joints defined by the boundaries of mechanisms. It is a form of scientific progress when kinds previously thought to be diverse, such as burning, rusting, and breathing, are found to all be explained by a common type of mechanism, oxidation. And it is also a form of scientific progress to recognize that a single phenomenon, such as memory, is more perspicuously split into several distinct types of phenomena (such as echoic, procedural, semantic and episodic memory). This raises the question of whether the proper taxonomy for a higher-level science can be “read off” of, or otherwise objectively grounded in, the antecedently intelligible mechanistic structure of the world.

Boyd’s 1991, 1997 homeostatic property cluster view holds that special science kinds are clusters of regularly co-occurring properties whose co-occurrence is explained by a mechanism; such kinds are to be “accommodated” to the causal structure of the world, lumping and splitting as necessary to bring the taxonomy of kinds into maximum alignment with the mechanistic structure of things (see, e.g. Wilson and Baker XXXX). Bechtel 1986 argues that etiological mechanisms of selection ground claims about teleologically-defined higher-level kinds. Others emphasize the importance of “looping kinds” in the human and social sciences in which labels can bring new kinds into existence via social mechanisms (Kuorikoski and Pöyhönen 2012). Still other mechanists, such as Craver 2009, 2013, have argued for a kind of perspectival pluralism about higher-level kinds based on the complexity and heterogeneity of the world’s mechanistic and hierarchical structure. A view with similar consequences is developed by Glennan 2017, whose nominalism identifies higher-level kinds wherever there is a useful model referring to that kind. Indeed, Kalidi 2013 argues for a simple causal theory of natural kinds, which might or might not be underwritten by deeper mechanistic structure.

In the cognitive sciences, some suggest that the border between mind and world is located at interfaces between mechanisms (Haugeland 1998; Kaplan 2012). To the extent that mechanisms cross the boundaries of the skin, then, one might have an objective basis on which to claim that tools and behaviors are part of the mind. Baumgartner and Wilutzky 2017 argue that the natural boundaries of mechanisms cannot possibly serve this purpose.

Baumgartner, M., & Wilutzky, W. (2017). Is it possible to experimentally determine the extension of cognition? *Philosophical Psychology*, *30*(8), 1104–1125. http://doi.org/10.1080/09515089.2017.1355453
Argue that mutual manipulability cannot be used to settle the extension of cognition, as how far it extends depends on pragmatic choices having to do with how one characterizes the phenomenon in the first place.

Boyd, R. (1991). Realism, Anti-Foundationalism, and the Enthusiasm for Natural Kinds. *Philosophical Studies*. *61*(1-2), 127–148. https://doi.org/10.1007/BF00385837
Boyd develops the HPC view of natural kinds in the special sciences as middle-ground between constructivism and essentialism. He argues HPC kinds are “determined by the causal structure of the world” and “independent of our conventions or our theorizing.”

Boyd, R. (1997). Kinds as the “Workmanship of Men”: Realism, Constructivism, and Natural Kinds, in J. Nida-Rumelin (ed.), Rationality, Realism, Revision: Proceedings of the 3rd International Congress of the Society for Analytical Philosophy, New York: Walter de Gruyter, pp. 52–89. https://doi.org/10.1515/9783110805703.52
Extends the HPC view, elaborating on its internal commitments and expounding upon its reliance on the ideas of mechanism and “accommodation” to the world’s causal structure.

Craver, C. F. (2009). Mechanisms and Natural Kinds. *Philosophical Psychology. 22*(5), 575 – 594.
Argues that the HPC view of kinds regresses and, short of that, presumes an antecedent mechanistic structure that cannot, in fact, be read off the world’s complex and heterogeneous causal structure.

Craver, C. F. (2013). Functions and Mechanisms: A Perspectivalist View. *Functions: Selection and Mechanisms*, 133–158. http://doi.org/10.1007/978-94-007-5304-4
Argues for the importance of downward, backward, and upward- and outward-looking perspectives on mechanisms and their behaviors. Functions and mechanisms are defined only relative to some explanatory interest and are, in this sense, perspectivally dependent.

Glennan, S. (2017). *The New Mechanical Philosophy*. Oxford University Press: Oxford.
Develops a model-based, nominalist theory of natural kinds according to which there are kinds wherever there are magnitudes or features represented by a useful model.

Kalidi, M. A. (2013). Natural Categories and Human Kinds: Classification in the Natural and Social Sciences. Cambridge: Cambridge University Press.
Develops the view that natural kinds are nothing more or less than nodes in a causal network.

Kaplan, D. M. (2012). How to demarcate the boundaries of cognition. *Biology and Philosophy*. *27*(4), 545–570. http://doi.org/10.1007/s10539-012-9308-4
Applies the mutual manipulability account to provide a criterion for saying when external features of the environment are constitutively relevant to the mechanism in question.

Kuorikoski, J. and S. Pöyhönen. (2012). Looping Kinds and Social Mechanisms. *Sociological Theory*. *30*(3), 187–205. https://doi.org/10.1177/0735275112457911
Defends the idea that many social-level kinds are homeostatic property cluster kinds sustained in part by so-called looping mechanisms, in which categorization according to a conceptual scheme is part of the causal structure by which the cluster of co-occurring properties is maintained.

Wilson, R.A., Barker, M.J. and Brigandt, I. When Traditional Essentialism Fails: Biological Natural Kinds. *Philosophical Topics* 35: 189-215.

Defends a homeostatic property cluster view of natural kinds in contrast to both essentialism and nominalism about biological kinds.

11. Functionalism, Abstraction, and Mechanisms

Mechanists have tended to emphasize the importance of knowing mechanistic detail in distinguishing mechanistic explanations from phenomenological descriptions (Kaplan and Craver 2011). And they have tended to describe completeness as a dimension along which explanations might be assessed (Craver 2007). Kaplan and Craver 2011 also argue for a model-to-mechanism mapping (3M) to distinguish mechanistic explanations from phenomenal descriptions, a thesis many authors associate with an unrestrained drive for more detail (see also Kaplan 2012). Finally, Piccinini and Craver 2011 argue that psychological explanations should be evaluated as mechanism sketches: promissory notes on a future complete mechanistic description. In each case, these claims are contrasted with a functionalist consensus, according to which there are explanations that gloss over details about, for example, how psychological functions are implemented in neural mechanisms. Mechanists have tended to emphasize the extent to which any viable notion of adequacy for psychological (and other high-level explanations) must honor facts about the mechanisms by which those functions are implemented.

Each of these claims has attracted criticism from those who emphasize the importance of abstraction in scientific understanding. Thus Bokulich 2011 argues against an ontic conception of explanation on the grounds that it cannot handle abstraction and idealization. And Weiskopf 2011 and Egan 2017 object to the drive for mechanistic explanation on the grounds that there are perfectly legitimate functional and informational-theoretic explanations that lack details about underlying mechanisms. These criticisms, have in turn, attracted responses, e.g., from Povich 2017, who defends the effort to map cognitive ontology to neural mechanisms, and from Zednik 2015 who emphasizes that explanatory completeness is pragmatically bracketed by available representational tools. Craver and Kaplan 2018 clarify the mechanistic views about the nature of explanatory completeness. They argue that abstraction and idealization are meaningful notions only against the backdrop of a world replete with relevant detail from which one might abstract or idealize. Relevant details might be found at many levels, and not all details are relevant to every, contrastively formulated explanandum. Mechanists have only ever required that explanatory models include explanatorily relevant details; not that they include all details, or even all unrestrictedly relevant details. Glennan 2017 discusses how models are applied to particular systems, stressing the role of categorization in decisions about mechanistic and phenomenal kinds and in deciding the appropriate level of organization in explanation.

Bokulich, A. (2011). How scientific models can explain. *Synthese*, *180*(1), 33–45. http://doi.org/10.1007/s11229-009-9565-1

Argues that defenders of the ontic conception cannot accommodate the fact that models in the sciences are often abstract and idealized. She defends a model-based account of explanation on the grounds that it explicitly avoids these limitations.

Craver, C.F. and Kaplan, D. (2018). Are More Details Better? On the Norms of Completeness for Mechanistic Explanations. *British Journal for the Philosophy of Science.* https://doi.org/10.1093/bjps/axy015

The authors clarify their 3M requirement and situate it with respect to other putative explanatory norms. They discuss how it is expected in light of the ontic conception of explanation that models function as abstract and idealized tools for describing a complex and messy world.

Egan, F. (2017). Function-Theoretic Explanation and the Search for Neural Mechanisms. In D. M. Kaplan (Ed.) *Integrating Mind and Brain Science: Mechanistic Perspectives and Beyond*. Oxford University Press.
Argues, contra Craver and Kaplan, that function-theoretical models have explanatory content even if they do not describe the mechanisms responsible for the phenomenon in question.

Glennan, S. (2017). *The New Mechanical Philosophy*. New York: Oxford University Press.
Considers how particular phenomena are typed under abstract models as a component in a nominalist theory of natural kinds.

Kaplan, D. M., & Craver, C. F. (2011). The Explanatory Force of Dynamical and Mathematical Models in Neuroscience: A Mechanistic Perspective. *Philosophy of Science*, *78*(4), 601–627. http://doi.org/10.1086/661755
The authors argue that any theory of mechanistic explanation must distinguish explanations from phenomenal models. They propose the 3M (model-to-mechanism-mapping) requirement that an explanatory model must describe one or more features of the mechanism if it is to have explanatory content.

Levy, A. and Bechtel, W. (2012). Abstraction and the Organization of Mechanisms. *Philosophy of Science*, *80*(2), 241–261. https://doi.org/10.1086/670300
The authors emphasize the importance of abstraction in network models to argue for the relevance of non-mechanistic explanations.

Piccinini, G., & Craver, C. F. (2011). Integrating Psychology and Neuroscience: Functional Analyses as Mechanism Sketches. *Synthese*. *183*(3), 283-311. http://doi.org/10.1007/s11229-011-9898-4
Argues that psychological explanations should be conceived as mechanism sketches to be filled in by descriptions of mechanisms. Psychological explanation in the scientific domain is either mechanistic or unworthy of the name.

Povich, M. (2015). Mechanisms and Model-Based Functional Magnetic Resonance Imaging. *Philosophy of Science*. *82*(5), 1035-1046. https://doi.org/10.1086/683438
Argues, against Weiskopf, that psychological models must embody commitments to facts about the causal structure if they are to carry explanatory force. He shows further that scientists engaged in putatively functionalist research in fact favor methods that tie their theories to facts about mechanistic structure.

Weiskopf, D. A. (2011). Models and mechanisms in psychological explanation. *Synthese*, *183*(3), 313–338. http://doi.org/10.1007/s11229-011-9958-9
Argues, contra Piccinini and Craver, that psychological explanation often proceeds independently of knowledge of lower-level mechanisms. It is possible to sort good and bad explanations without appealing to knowledge of underlying mechanisms.

Zednik, C. (2015). Heuristics, Descriptions, and the Scope of Mechanistic Explanation pp. 295–318. Springer, Dordrecht. http://doi.org/10.1007/978-94-017-9822-8_13
Argues that the amount of detail one is required to use in an explanation might well depend on the representational tools available. In an age of big-data and complex computational models, more and more mechanistic detail can be represented.

12. Levels of Mechanisms and Interlevel Causation

Craver (see his 2007 under *Central Articles and Books*) describes levels of mechanism as of singular explanatory import (see Craver and Povich 2016 for a review; *Mechanisms, Reduction, and Interfield Integration*). Mechanistic levels are defined in terms of a relevance relationship between wholes and their parts that distinguishes working parts from mere spatio-temporal chunks. Craver suggests as a sufficient condition for interlevel relevance that a part should be mutually manipulable with the behavior of the mechanism as a whole. This view of interlevel relevance has been charged with incoherence (e.g., Leuridan 2012; Baumgartner and Gebharter 2015)). Romero 2015 puts the problem in an inconsistent triad: If mechanists embrace an interventionist theory of causal relevance, and if the interlevel experiments for testing mutual manipulability are possible, then mechanists appear to be committed to accept the existence of interlevel causal relations that they argue are conceptually incoherent. Different solutions have been presented (see Kästner and Andersen 2018 for a review). Some understand constitutive relevance causally (Leuridan 2012); others appeal to fat-handedness (Romero 2015, Baumgartner & Gebharter 2015) or, alternatively, to causal relations between the components and temporal phases of the phenomenon (Krickel 2017), or finally, to causal in-betweenness (Harinen 2018). Couch (2011) and Harbecke (2010), in contrast, provide a description of constitutive relevance in non-interventionist terms borrowing Mackie’s notion of an INUS condition.

One consequence of the view that mechanistic levels relate wholes and their parts is that levels of mechanisms are defined only locally, relative to a top-level phenomenon one seeks to understand. This has been criticized by authors who demand that a respectable theory of levels must say when two items are at the same level (Eronen 2013). Craver dismisses the idea of monolithic levels of nature as scientifically irrelevant and also rejects the demand to say when two things are at the same level (see Craver and Povich 2016).

A further issue is as to whether there can be causal interactions between mechanistic levels. Craver and Bechtel 2007 argue that interlevel causation among levels of mechanisms is conceptually confused. This is because levels relate wholes and their parts, and that cause and effect must be wholly distinct, without overlap. Instances of putative interlevel causation, Craver and Bechtel argue, should be understood in fact as hybrid causal and constitutive claims. For an overview of different arguments against interlevel causation in mechanisms see Romero 2015. Krickel 2017, however, argues that interlevel causation in mechanisms is possible if mechanisms and their phenomena are viewed as temporally extended processes where the phases of each process make a causal difference to the phases of the respective other process.

Baumgartner, M., & Gebharter, A. (2015). Constitutive Relevance, Mutual Manipulability, and Fat-Handedness. *British Journal for the Philosophy of Science*, *67*(3), 731–756. http://doi.org/10.1093/bjps/axv003
Provide a detailed presentation of the problematic implications of the interventionist interpretation of constitutive relevance. They provide a solution in terms of fat-handed interventions.

Couch, M.B. (2011). Mechanisms and Constitutive Relevance. *Synthese*, *183*(3), 375–88. https://doi.org/10.1007/s11229-011-9882-z
Provides a regularity account of mechanistic constitution in terms of Mackie's INUS conditions.

Craver, C. F., & Bechtel, W. (2007). Top-down Causation Without Top-down Causes. *Biology & Philosophy*. *22*(4), 547–563. http://doi.org/10.1007/s10539-006-9028-8
Argue that any apparent claim about interlevel causation can be interpreted in terms of mechanistically mediated effects.

Eronen, M. I. (2013). No Levels, No Problems: Downward Causation in Neuroscience. *Philosophy of Science*. *80*(5), 1042–1052. http://doi.org/10.1086/673898
Argues that Craver's account of levels of mechanisms is problematic as it does not provide a criterion for being at the same level and mechanistically mediated effects. He suggests getting rid of the notion of a level and rather speak of composition and scale.

Harbecke, J. (2010). Mechanistic Constitution in Neurobiological Explanations. *International Studies in the Philosophy of Science*. *24*(3), 267–285. https://doi.org/10.1080/02698595.2010.522409
Develops a regularity account of mechanistic constitution based on the notion of a minimal type relevance theory.

Harinen, T. (2018). Mutual Manipulability and Causal Inbetweenness. *Synthese*, *195*(1), 35–54. http://doi.org/10.1007/s11229-014-0564-5
Interprets the phenomenon of a mechanistic explanation as a causal relation between an input into a mechanism and an output of a mechanism. Mutual manipulability, then, consists of an intervention into the input with respect to the mechanism, and an intervention into the mechanism with respect to the output—which are both clearly causal.

Kästner, L. and Andersen, L.M. (2018). Intervening into Mechanisms: Prospects and Challenges. *Philosophy Compass 13*(11), e12546. http://doi.org/10.1111/phc3.12546
Summarize the current state of the discussion of interventionist interpretations of constitution and present Kästner's solution of weakening interventionism as an approach for discovering general dependence relations rather than causal relations.

Krickel, B. (2017). Making Sense of Interlevel Causation in Mechanisms from a Metaphysical Perspective. *Journal for General Philosophy of Science*, *48*(3), 453–468. doi:10.1007/s10838-017-9373-0
Provides an analysis of the central argument against interlevel causation in mechanisms and shows how it can be rejected based on re-interpretation of the top-level phenomenon in terms of a temporally extended process.

Leuridan, B. (2012). Three Problems for the Mutual Manipulability Account of Constitutive Relevance in Mechanisms. ***British Journal for the Philosophy of Science*****,** ***63*****(2), 399–427. http://doi.org/10.1093/bjps/axr036**
An early criticism calling attention to the potential problems of the interventionist interpretation of constitutive relevance and of defining the relevant notion of a level of organization.

Romero, F. (2015). Why there isn't inter-level causation in mechanisms. ***Synthese*****.** ***192*****(11), 3731–3755. http://doi.org/10.1007/s11229-015-0718-0**
Provides a useful summary of debates over interlevel causation in the form of an inconsistent triad of commitments: an interventionist theory of causation, the mutual manipulability account of constitutive relevance, and the prohibition on interlevel causation. Among the first to suggest a solution appealing to the fat-handedness of top-down causal claims.

13. Dynamical Models, Minimal Models, and Network Models: Conflict or Cooperation?

To explore the limits of mechanistic explanations, many scholars have begun to explore scientific models that appear to carry explanatory weight but that do so, not in virtue of describing mechanisms but because they achieve some other explanatory aim, such as descriptive economy and scope. Dynamical explanations, network models, and so-called minimal models have all be proposed as contrast classes.

Chemero and Silberstein 2007 argue that certain areas of cognitive science call out for dynamical explanations that characterize the temporal evolution of a system in terms of differential and difference equations. Such systems, they argue, have no parts, properly so-called, as tightly coupled interactions foil decomposition. Kaplan and Craver 2011 argue that some dynamical models (such as the HKB model of bimanual coordination that is the focus of these discussions) merely characterize a behavioral phenomenon (phase transitions in the wagging of index fingers) and do nothing to explain why the phenomenon is as it is (why the phase transition happens when it does; see also Zednick 2010).

Some contrast mechanistic explanations with network explanations both because they are abstract (Levy and Bechtel 2013; see *Functionalism, Abstraction, and Mechanisms*) and because highly complex networks, like the brain or cellular signaling cascades, cannot readily be decomposed into parts (Rathkopf 2016). Huneman 2016 argues that such explanations are topological in that they show the phenomenon to be the derivational consequence of the existence in the system of a certain topological structure. Craver 2016 argues that genuinely explanatory network models have explanatory force in virtue of revealing relevant portions of the world's causal structure.

Finally, recent attention to minimal model explanations emphasizes the search for compact and abstract expressions of key relevant features in a target system, often gaining significant predictive power with remarkably simple formal models, which often have little to do with the known ontic structure of the system in question (Batterman and Rice 2014, Chirimuutta 2014). Povich 2016 responds that such explanations require for their simplicity and effectiveness key background assumptions about the very causal structures that such models explain, without which the explanations would collapse.

From the ontic perspective, the explanatory power of a model follows from the fact that it conveys information about the mechanism in question. Different patterns in the causals structure of a mechanism might be most perspicuously represented with different kinds of models or in different formalisms (Hochstein 2017).

Batterman, R. W. and Rice, C. (2014). Minimal Model Explanations. *Philosophy of Science 81*(3), 349–376. http://doi.org/10.1086/676677
Argue for the importance of minimal model explanations and for the danger of assuming that more details always improve an explanation, a thesis the authors attribute to the mechanists.

Chemero, A. and Silberstein, M. (2007). After the Philosophy of Mind: Replacing Scholasticism with Science. *Philosophy of Science*. *75*(1), 1-27. http://doi.org/10.1086/587820
Argue that dynamical explanations are different in kind from mechanistic explanations as they do not describe interactions among parts but rather characterize the evolution of the system as a whole in terms of system-level variables.

Chirimuuta, M. (2014). Minimal Models and Canonical Neural Computations: The Distinctness of Computational Explanation in Neuroscience. *Synthese*. *191*(2), 127–153. http://doi.org/10.1007/s11229-013-0369-y
Charges mechanists with embracing the thesis that more details always improve an explanation. Argues for the import of interpretive minimal models that explain phenomena in terms of their optimization of information transmission.

Craver C. F. (2016). The Explanatory Power of Network Models. *Philosophy of Science*. *83*(5), 698-709. https://doi.org/10.1086/687856
Argues that network models have their explanatory force in virtue of describing relevant features of a mechanism. Shows that mathematical theories of network explanation face counter-examples and criticizes Rathkopf's contrast between network models and mechanistic explanations.

Huneman, P. (2010). Topological explanations and robustness in biological sciences. *Synthese 177*(2), 213-245. https://doi.org/10.1007/s11229-010-9842-z
Argues that network and other topological models carry explanatory force in virtue of subsuming empirical phenomena under maximally general mathematical truths.

Kaplan, D. M., & Craver, C. F. (2011). The Explanatory Force of Dynamical and Mathematical Models in Neuroscience: A Mechanistic Perspective. *Philosophy of Science*, *78*(4), 601–627. http://doi.org/10.1086/661755
Argue that any theory of mechanistic explanation must distinguish explanations from phenomenal models. They propose the 3M (model-to-mechanism-mapping) requirement that an explanatory model must describe one or more features of the mechanism if it is to have explanatory content.

Matthewson, J. and Calcott, B. (2011). Mechanistic Models of Population-Level Phenomena. *Biology and Philosophy 26*(5), 737-756.
Warns against conflating claims about mechanisms with claims about models, embracing a view similar to those who endorse the ontic conception of explanation. As applied to debates about natural selection: the question is not whether it is a mechanism but rather whether it can be modeled usefully as a mechanism of a particular sort.

Povich, M. A. (2016). Minimal models and the generalized ontic conception of Scientific Explanation. ***British Journal for the Philosophy of Science. 69*****(1), 117-137.** **https://doi.org/10.1093/bjps/axw019**
Argues contra Batterman and Rice that only an ontic conception of explanation can explain the range of applicability of the minimal models in question and that Batterman and Rice lack the resources to satisfy their own desiderata on an account of explanation.

Rathkopf, C. (2015). Network representation and complex systems. ***Synthese. 195*****(1), 55-78. http://doi.org/10.1007/s11229-015-0726-0**
Rathkopf argues that network models offer a distinctive leverage over system complexity for representing non-decomposable systems and for delivering useful algorithms in searching for network organization.

Zednick, C. (2010). The Nature of Dynamical Explanation. ***Philosophy of Science*****.** ***78*****(2), 238-263. https://doi.org/10.1086/659221.**
Argues that examples of dynamicist explanation fail to count against mechanistic theories of explanation but, nonetheless, point to the need to enrichen theories of mechanistic explanation to handle temporal dynamical and complexity.

14. Objections from the Failure of Localization and Decomposition as a Strategy

The idea of mechanism goes hand in hand with scientific strategies of discovery through reverse engineering, that is, through the decomposition of working systems into their component parts. Some critics of mechanism argue that this commitment to the idea of parts intelligible independently of their causal relations to one another in complex dynamical systems is outdated thinking that must be abandoned to appreciate especially biological systems. It is argued that these localization and decomposition are incompatible with the dynamic and living nature of biological phenomena (Moss 2012; Silberstein & Chemero 2013; Dupré 2013; Austin 2017). Others have attempted to expand the mechanistic approach by thinking about how multiple higher-level functions might be reorganized through the rededication of overlapping modules in different task contexts (Anderson 2016), rearranging how we think about the mapping relationship (if it can be so-called) between higher-level phenomena and lower-level mechanisms. Despite the criticisms, mechanistic theories of explanation have been used to design biological databases for storing mechanistic knowledge about how genes and disease phenotypes are related (Darden et al. 2018) and network modelling techniques are increasingly being used to tame the complexity of biological systems (Rathkopf 2015, and new computational approaches are being used to model even very complex interactions in dynamic networks (Casini et al 2011; Gebharter 2018). The death of mechanism has been predicted before and is perhaps being advertised a bit prematurely in these cases as well. Time will tell.

Austin, C. J. (2017). The Philosophy of Biology. ***Analysis*****,** ***77*****(2), 412–432.** **http://doi.org/10.1093/analys/anx032**
Austin provides an extensive and summary of the debate over the objections against the new mechanistic account based on a rejection of localization and decomposition and the idea that machine-like, step-wise modes of understanding might well have run out of steam in the face of biological complexity.

Anderson, M. (2016). Precis of After Phrenology. *Behavioral and Brain Sciences. 39*, e120. https://doi.org/10.1017/s0140525x15000631
While not a critic of localization or decomposition, simpliciter, Anderson describes the ways that distinct psychological mechanisms might be implemented in overlapping biological mechanisms organized differently and perhaps behaving differently in different contexts.

Casini, L., Illari, P. M., Russo, F., & Williamson, J. (2011). Models for prediction, explanation and control: Recursive Bayesian networks. *Theoria*, *26*(1), 5–33. http://doi.org/10.1387/theoria.784
The authors apply the Recursive Bayesian Net (RBN) formalism, that stands in the tradition of interventionist modelling, to the hierarchical structure of mechanisms.

Darden, L. Kundu, K., Pal, L.R., and Moult, J. (2018). Harnessing formal concepts of biological mechanism to analyze human disease. *PLOS Computational Biology*. https://doi.org/10.1371/journal.pcbi.1006540
Uses the mechanistic framework for biology as the scaffolding for a database of mechanistic knowledge linking genotypic differences via intermediate molecular and other mechanisms to phenotypes.

Dupré, J. (2013). Living Causes. *Aristotelian Society Supplementary Volume 87*(1), 19–37. http://doi.org/10.1111/j.1467-8349.2013.00218.x
John Dupré rejects the new mechanists' entity-activity dualism for the reason that there are no stable entities in biology; there are only stable processes.

Gebharter, A. (2017). *Causal Nets, Interventionism, and Mechanisms*. Cham: Springer International Publishing. http://doi.org/10.1007/978-3-319-49908-6
Develops a way to apply formal analysis of causal Bayes' nets to provide an interventionist analysis of mechanisms that can accommodate the dynamical structure of biological reality.

Moss, L. (2012). Is the philosophy of mechanism philosophy enough? *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, *43*(1), 164–172. http://doi.org/10.1016/j.shpsc.2011.05.015
Moss argues that the goal of the life sciences is not to decompose biological systems in order to localize mechanistic components at all levels of the hierarchy to finally reach a complete how-actually explanation.

Rathkopf, C. (2015). Network representation and complex systems. *Synthese. 195*(1), 55-78. http://doi.org/10.1007/s11229-015-0726-0
Argues that network models offer a distinctive leverage over system complexity for representing non-decomposable systems and for delivering useful algorithms in searching for network organization.

Silberstein, M., & Chemero, A. (2013). Constraints on Localization and Decomposition as Explanatory Strategies in the Biological Sciences. *Philosophy of Science*, *80*(5), 958–970. **http://doi.org/10.1086/674533**

Present several examples where localization and decomposition apparently fail. They argue that the new mechanistic account either has to be modified or that some phenomena do not have a mechanistic explanation.