Realization: Metaphysics, Mind, and Science

Robert A. Wilson†‡

This paper surveys some recent work on realization in the philosophy of mind and the philosophy of science.

1. Introduction. While the concept of realization has been invoked in the philosophy of mind and psychology for over 40 years, it has only recently become the subject of philosophical theorizing. The most common context in which philosophers have talked of realization is in discussion of the relationship between mental and neural states. Located at the interface between traditional metaphysics and the philosophy of mind, on the one hand, and the philosophy of science and of the cognitive sciences in particular, on the other, realization has been called upon to play many different roles. This paper provides some sense of the distinct views of realization by discussing four recent proposals in the literature. It suggests both that there are a number of "choice points" in thinking about realization, and that there is much to be gained by ensuring that the more a priori and more naturalistic ends of the spectrum of views of realization inform one another.

2. Preliminaries. Hilary Putnam introduced the concept of realization into the contemporary literature in the philosophy of mind in 1960 in his classic paper "Minds and Machines." Putnam described the relationship between the mental and the physical as one of realization on the basis of

†To contact the author, please write to: Department of Philosophy, 4-115 Humanities, University of Alberta, Edmonton, Alberta, T6G 2E5, Canada; e-mail: rob.wilson@ualberta.ca.

‡I would like to thank Carl Craver for both the invitation to participate in the PSA symposium on realization and neuroscience and his comments on the penultimate version. Thanks also to my coparticipants and the PSA audience for further food for thought.

Philosophy of Science, 71 (December 2004) pp. 985–996. 0031-8248/2004/7105-0030$10.00

an analogy to the relationship that, he claimed, holds between abstract Turing machines and the physical arrangements of matter in which they are instantiated or implemented. Part of Putnam's point was to *dissolve* the mind-body problem. For he claimed that the relationship between mind and body, or mind and brain, should be no more puzzling—indeed, no more interesting—than that between the abstract states of a given Turing machine and the structural states of the device realizing it.

Without recounting any further history here, I simply note how readily this talk of realization became embedded within the discussions of three "isms" that came to dominate the philosophy of mind and psychology over the next decade or so: physicalism, functionalism, and reductionism. More recent discussions of mental causation, especially those in and derivative from the work of Jaegwon Kim, have continued this tradition, often being cast in terms of the significance of the putative *multiple realizability* of mental states for these three "isms" and the relationships between them.

Putnam's original introduction of "realization" also formed a part of the "cognitive revolution" that spawned the cognitive sciences as we know (and love) them. In doing so, it also provided a way of thinking about the relationship between the mental and the physical taken up within psychology, linguistics, and computer science themselves. At least that is part of philosophical lore. The idea was something like this. Even if we did not hear the term "realization" in the mouths of those working within these disciplines, their explorations of the mechanisms underlying psychological functions, capacities, and abilities could be adequately glossed in terms of more metaphysical-sounding notions, such as supervenience and realization. Talk of the *neural correlates* of, or of the *neural mechanisms* for, a given psychological capacity was loose science-speak for something like the relation of realization.

I singled out the contemporary "hot topic" of mental causation to illustrate the continuing importance of realization within the philosophy of mind. Correspondingly, perhaps we can identify the recent focus within the cognitive sciences on the *localization* of psychological functions—the study of which has intensified with the development of imaging techniques, such as PET and fMRI, in the last 20 years—and its relationship to philosophical discussions of realization, as illustrating the continuation of an earlier tradition of interplay between philosophers of *x* and *x*-ists.

The slack that exists between talk of neural correlates and mechanisms within the cognitive sciences proper and philosophical glosses cast in terms of realization deserves at least a brief comment. The short answer to the question "How do *cognitive scientists* conceptualize realization?" is "They don't." Or, to put it more accurately: they do, but almost exclusively when they are attempting to sketch a broader location for their particular views

or to interact directly with their philosophical interlocutors. Given that, the assumption that we can gloss science-speak of the physical correlates of, the underlying mechanisms for, or localized structures causally implicated in, the operation of some particular psychological capacity in terms of the notion of realization may not be cost free. It may require that we adjust our view of what appeals to "realization" can do, or leave us with a philosophically emaciated view of realization (cf. also Polger's discussion of Marr on realization (2004)).

3. Four Easy Pieces. In this section I shall outline four recent approaches to realization that vary in how tightly they focus on psychological states and capacities. Three aims: first, to provide a sense of some of the diversity that exists in views of realization and the work that the concept is put to; second, to show what sorts of broader issues these accounts raise for thinking about the metaphysics and science of mind; and third, to make a prima facie case (even if only in passing) for the need to keep both a priori and a posteriori considerations in mind in developing and deploying the concept of realization.

Consider, first, a short discussion of realization by Carl Gillett (2002). Gillett's focus is on the work of Kim (1998) and Shoemaker (2001), and the basic idea of the paper is to show that there is a fatal counterexample to the view of realization that they share—what Gillett calls *the standard view*—that motivates an alternative view of realization. The standard view is a conceptual analysis of what it is for a property instance X to realize a property instance Y, and has the following two necessary conditions:

1. X and Y are instantiated in the same individual
2. the causal powers individuative of Y match the causal powers contributed to X.

The talk of "matching" in condition 2 is to be understood to allow that X may have causal powers in addition to those that Y has, but it has at least all the powers that Y has.

The counterexample to the standard view that Gillett produces is the familiar property of hardness (say, in a diamond), which is usually thought of as realized by the constituent molecules of the diamond and how they are arranged. If this is a case of realization, then condition 1 is violated because the individual that instantiates the property of hardness is the diamond, while what does the instantiating is in some part of that individual, not the individual itself. Likewise, condition 2 is violated because the causal powers of the two relevant levels involved, that of the individual (the diamond) and that of its constituents (the molecules) are not related subsumptively; they are, rather, simply different sets of causal powers. Gillett thinks, more generally, that to make sense of realizers at "lower

levels" than the properties they realize, we need to give up both 1 and 2, and hence the standard view. Gillett's alternative to the standard view is the following:

> Property/relation instance(s) F1–F*n* realize an instance of property G, in an individual *s* if and only if *s* has powers that are individuative of an instance of G in virtue of the powers contributed by F1–F*n* to *s* or *s*'s constituent(s), but not vice versa. (322)

I omit direct discussion of this view of realization, and do not attempt to evaluate either the accuracy of Gillett's characterization of the views of Kim and Shoemaker, or the depth of his critique of the standard view. The chief point I want to draw attention to concerns what I'll call the *metaphysical rarification index*: it is quite high. This is in part because of the exclusive focus on properties and their instances; in part it is due to the correlative talk of *powers* and *individuation*; and in part it is a function of the traditional methodology of conceptual analysis. One consequence of this high metaphysical rarification index is that it is difficult to know how best to generalize from views such as the standard view, or Gillett's own view, to views that talk of the realization of objects, of functions or capacities, or of processes.

A secondary point is about properties themselves and our common ways of talking about them. You don't have to be a fan of sewing, or even David Hume, to think of properties as being *in* individuals, as pins in a pincushion. Both conditions 1 and 2 in the standard view owe much to the idea that the causally important properties in the world inhere in individuals. This idea seems especially captivating in conceptions of *mental* properties. Views of the mental that reject this idea of inherence—such as externalism (mental properties as relational properties) or Wittgen-Ryleanism (mental properties as acts)—are often charged with causing epiphobia, a form of public nuisance to be frowned on by serious materialists.

Gillett's view of realization shares with the standard view this conception of properties, and so realizations, as inhering in individuals. Anyone offering a theory of properties also acknowledges that there must be a corresponding theory of relations, and it is typically assumed that their account of the former can also be modified or extended to provide an account of the latter. But, pray, what individuals are relations "in"? The natural answer is that they are not in individuals, but *between* them; not pins in a pin-cushion but the cement of the universe. The real problem is that both the standard view and Gillett's own alternative to it lead us to think of realizations as being *physically inside* individuals, and so as something like *part of* those individuals.

The second view of realization is my own (Wilson 2001) and it can be

introduced in light of what we have seen in Gillett's discussion. Like Gillett's paper, my own introduces a novel account of realization by means of contrast with an existing, partially implicit view that accepts two theses. These are the *sufficiency thesis*: realizers are metaphysically sufficient for the properties or states they realize; and the *constitutivity* thesis: realizers are exhaustively physically constituted by the intrinsic, physical properties of the individuals who have them. The discussion is motivated specifically by the individualism vs. externalism issue in the philosophy of mind, and by skepticism about the view I have elsewhere (Wilson 1999) called *smallism*, metaphysical discrimination in favor of the small, and so against the not-so-small.

The critical argument of the paper is that these two theses, despite being widely endorsed in the philosophy of mind, are not jointly satisfied in a range of cases. Its constructive component suggests that realization is *context sensitive*. One form that such context-sensitivity takes is that of *wide* realizations, realizations that extend beyond the boundary of the individuals who have the corresponding property. The critical and constructive aspects of the view are linked via the claim that in accepting the constitutivity thesis philosophers have focused exclusively on one kind of realization, *entity-bounded* realization, whereas you need both entity-bounded and wide realizations in order to provide an account of the full range of properties postulated across the sciences. Entity-bounded realizations are exemplified by the case of physiological systems, such as the circulatory or digestive system, and these systems and the properties they realize are individualistic. By contrast, wide realizations are exemplified by ecological systems, such as the predator-prey system. The claim is that a range of *psychological* properties in fact have wide rather than entity-bounded realizations.

In situating itself against predominant views of realization, this view (like Gillett's) has a high metaphysical rarification index. Unlike Gillett's view, however, this context-sensitive view of realization is developed in tandem with an account of strategies of explanation across a range of sciences. Entity-bounded realizations motivate a methodology of *constitutive decomposition*, a methodology familiar in the physical sciences and that finds expression in the philosophy of mind in how *homuncular functionalism* is typically viewed. By contrast, wide realizations motivate a methodology of *integrative synthesis*, whereby the individual with a given property is itself located within some larger system.

The central unexplicated notion in this view of realization is that of a *system*, and we might have doubts about whether that notion is robust enough to do the work required of it. The key idea is that while one kind of entity *possesses* or *has* a given property, that property is realized in or by another kind of entity, a system. In standard cases, the possessing

entity is an individual, and the systems may either form a part of that individual (in the case of entity-bounded realization) or be something of which that individual forms a part (in the case of wide realizations).

The requisite symmetry here presupposes that the systems that are parts of individuals are the same kind of thing that individuals are parts of. We might question whether this is true. The digestive system, for example, can be thought of as a kind of individual with its own properties, and parts that stand in specific causal relationships to one another. The predator-prey system, by contrast, is not itself a kind of individual, or if so it is an individual only in some extended sense. The same is true of other examples of wide systems given in Wilson 2001, such as that constituted by an organism and its niche (realizing its *fitness*), and the wide computational system for form perception (realizing the capacity of individual organisms to see basic visual forms).

As with my discussion of Gillett's views, my aim here is not to offer some ultimate assessment of this problem for the view, but to highlight some broader issues that it raises. In this case, these include whether there is an individualistic bias in the standard metaphysics of realization, whether realization should be understood uniformly across distinct scientific contexts, and how one might link together a metaphysical account of realization with methodological and explanatory practices in the sciences. An issue that requires further discussion, ultimately, concerns the notion of a system and how it is to be understood.

It is precisely this issue that is taken up in the third account of realization that I shall discuss, that of Lyons (2001). Lyons's chief interest is in the modularity-of-mind thesis that stems from Fodor (1983) and that has stimulated much current work in developmental psychology, neuroscience, and evolutionary psychology. At the core of this discussion is an analysis of the central and related notions of a *cognitive system* and of the realization relation. Lyons proposes the following views:

> *c* is a cognitive system for task *T* iff there exists some substrate *S* that realizes a system for *T* in virtue of realizing *c*.
>
> A substrate *S* realizes a system for *T* iff *S* is isolable, specialized, and unitary with respect to *T*. (cf. 2001, 290–291)

In turn, the three crucial notions in the analysis of realization are spelled out by Lyons as follows. Suppose that *S* performs *T*. Then *S* is:

> *isolable* iff this performance is not dependent on the computation of other cognitive functions.
>
> *specialized* iff *S* doesn't perform any other cognitive functions.
>
> *unitary* iff nothing less than the whole of *S* performs *T*. (cf. 289)

In short, *S* must be sufficient for *T*, not necessary for any other task, and compact. Thus, a realization of a system for a given cognitive task must perform this task by itself, not perform any other cognitive function, and be the smallest unit that satisfies these conditions. Cognitive systems are just those systems that are realized, in this sense, in the performance of cognitive tasks.

The first point to flag in considering this account here is that, unlike that of Gillett and my own, it focuses exclusively on cognition and is cast in terms of the notions of cognitive tasks, functions, and capacities. This provides the view with a direct connection to psychological methodology and explanation, since these are the central explananda in the cognitive sciences. In particular, Lyons's view links nicely to how cognitive scientists go about *testing* whether a given substrate is causally responsible for specific tasks, including the use of deficit studies and imaging techniques conducted under experimental conditions. The view is well suited to make sense of the *localistic* strategies of explanation, such as constitutive decomposition, that are prevalent in the cognitive sciences.

Indeed, the aptness of Lyons's view for such strategies raises the question of what it implies about nonlocalist strategies of explanation and the realization of cognitive states more generally. While there is nothing in Lyons's view as outlined above that entails that, in terms used above, cognitive systems have an entity-bounded rather than a wide realization, his more general comments suggest that the "substrates," and so systems, are proper parts of individual cognizers. On my view, this constitutes a smallist bias, albeit one that reflects that in the cognitive sciences themselves. It is also worth noting that the constraints that Lyons places on realization (and so on cognitive systems) make it difficult to see how to make sense of property-to-property realization of the kind central to more metaphysically rarified accounts. Either such talk should be abandoned or viewed with some skepticism, or Lyons's view requires a distinct account of property realization.

Relatedly, the conditions on realization would seem to rule out *multifunctional* cognitive systems (via the specialization constraint), and at least put pressure on the idea, increasingly popular through the influence of connectionist neural modeling, that cognitive capacities are realized in physically distributed neural systems. This is mainly because physically distributed cognitive systems, at least those that have actually been postulated, are more likely to violate at least the isolability constraint on realization. One could simply hold that there is no realization of and no cognitive systems for cognitive capacities, should they prove to be multifunctional or physically distributed. But then, of course, we are left at square one when it comes to developing an understanding of the metaphysical relation that holds between the mental and the physical.

One might wonder, in light of these points, how well Lyons's view generalizes as an account of realization (and system) beyond the cognitive domain. Lyons and I agree that the notion of a system is crucial to making sense of the concept of realization. I suggested above that the view of systems in Wilson 2001 may be insufficiently constrained; by contrast, we might wonder whether that in Lyons's account is too tightly constrained, being designed, as it was, specifically to shed light on cognition and claims of modular cognitive design.

Once the appeals to computation (in the isolability constraint) and to cognition are dropped, the account will say something like this: *S* realizes a system for *T* iff *S* itself does *T*, has no other relevant function, and is compact with respect to *T*. Consider again physiological systems, such as the circulatory system. It distributes nutrients around and removes waste products from the body. Since this system is literally built into the fabric of the organism itself, it is not clear that it performs these functions in and of itself, or how it is isolable from or independent of the performance of other biological functions. Likewise, consider the specialization constraint. I have expressed the task the circulatory system performs as a conjunct, and we could extend the list of conjuncts: the circulatory system keeps the body healthy, facilitates immune responses, oxygenizes the blood, and maintains hydration in the body. If we specify just one of these as the task of the circulatory system, then clearly the specialization constraint is violated. It is possible to hold that "the" task of the circulatory system is to do all of these things, but then this seems to depart from the idea that (cognitive) systems are specialized for accomplishing particular tasks. It may be, however, that just as we need to move away from thinking of (individual) mental states or properties as being realized in (individual) brain states or properties, this is precisely the further adjustment that needs to be made in developing an adequate conception of realization. Realizing systems themselves have a *functional complexity* and *physical embeddedness* that should give pause to thinking of them simply as things with a function lodged in other things, individuals.

The final view that I shall discuss is that of Carl Craver on *hierarchical mechanisms* (2001), which offers a synthesis of Cummins's views on functions with recent work on mechanisms by Machamer, Darden, and Craver (2000), Wimsatt (1996), Glennan (1996), and Bechtel and Richardson (1993). Although the notion of realization features only in passing in Craver's (2001) view, I want to suggest a number of connections between it and the work explicitly on realization that I have discussed so far (cf. also Craver 2004). In making these connections we should, however, keep in mind the earlier point about the gap between scientific usage and philosophical reconstruction.

Hierarchically organized mechanisms are central to the biological sci-

ences and to neuroscience, as is the ascription of functions that these mechanisms perform. The hierarchy that such mechanisms form is a part-whole hierarchy, such that any given mechanism is itself physically composed of other mechanisms, and in turn physically constitutes further mechanisms. Craver (2001) shares with Lyons (2001) a focus on the performance of given functions, on *activities*, and how these activities are accomplished, i.e., the mechanisms or realizations in virtue of which the activity is completed. And he shares with Wilson (2001) the idea that mechanisms or realizations have a contextual aspect that is often overlooked when one has an exclusive focus *on entities*.

Craver distinguishes three perspectives that one can take on a given activity that is part of a mechanistic hierarchy. First, we can view that activity as the isolated ϕ-ing of something. Second, we can "look down" in the hierarchy to identify the mechanisms whose activity constitutes that thing's ϕ-ing. And third, we can "look up" in the hierarchy to locate the contextual mechanism of which that thing's ϕ-ing is a part. The paradigm that Craver uses is one that we have already met in this paper: the contracting of the heart pumping blood within the circulatory system. In discussing this example, Craver says,

> The circulatory system has a hierarchical mechanistic organization. The activities ψ of the circulatory system S are instantiated by the heart's pumping of blood, the kidney's filtration of the blood, and the venous valves' regulation of the direction of blood flow (the ϕ-ing of the component Xs). (Craver 2001, 63).

Craver's talk of instantiation here suggests a natural connection to the views of realization we have already discussed.

As the continuation of the above passage suggests, Craver thinks of at least hierarchical mechanistic organization in physiology primarily in decompositional terms, starting with what I call an entity-bounded system, and then decomposing that system into its parts and how they function, and then applying this decompositional stem recursively. One question concerns the relationship between Craver's view of *contextual* mechanisms and the appeal that I have made to *wide* realizations. There are several reasons to be circumspect about simply identifying these.

First, in distinguishing his views from those of Bechtel on hierarchical levels, Craver emphasizes the perspectival character of his own appeal to constitutive and contextual mechanisms, and chides Bechtel for reifying the topmost level as *the* functional level. Rather, these levels are perspectives we can adopt in investigating the activity ϕ, with the idea being that we contextualize "up" in order to understand the *role* of ϕ and decompose "down" in order to discover the mechanisms through which ϕ operates (Craver 2001, 65–68). Wide realizations, then, might be thought

to suffer from a similar problem of reification in misconstruing the way in which contexts are related to functions.

Such a charge of reification seems to me mistaken. Craver himself is committed to the existence of constitutive mechanisms. This is an ontological commitment—to certain kinds of mechanisms—and I think we are all (including Bechtel) happy enough with this much reification. The question is what to say about "contextual mechanisms," and here I think Craver (2001) is more ambivalent. Appeals to these may be perspectival, heuristic, or pragmatically mandated, much as we might think are causal claims in general. But the entities invoked at such "higher levels" and their activities, such as the circulatory system and its supplying oxygen to the body, exist, as they must do so if *they* are to be mechanisms which in turn are decomposed into a series of entities performing their own activities. Thus, however a hierarchy *of perspectives* is invoked, it should not be used, in effect, to rule out a true hierarchy *of mechanisms* (cf. also Craver's Figure 2 (2001, 66)).

Second, a more direct way to approach this issue is to ask whether a mechanism, including a contextual mechanism, has to be localized within an individual, such as an organism. Like most philosophers writing on or invoking realization, Craver's focus is on a physiological paradigm, and the way in which he conceptualizes mechanisms primarily or asymmetrically in terms of decomposition reflects this focus. On my view (see Wilson 1999, 2001), this signals the potential for a smallist bias. But one might well reply that there *is* a genuine asymmetry between entity-bounded mechanisms and the contexts we invoke to discover or explain their operation. We might view this as akin to the putative asymmetry between entity-bounded *systems*, such as the circulatory system, and wide systems, such as the predator-prey system, that we postulated earlier. In fact, thinking more about mechanism in Craver's terms may shed light on this asymmetry.

One final thought on this. Paradigmatic mechanisms operate within systems (themselves often mechanisms) that are physically located within the boundaries of individuals. Individuals both operate and are located within environments. But surely neither individuals nor individuals-in-their-environments are themselves either systems or mechanisms, for they lack the crucial causal, spatial, and temporal organization that both systems and mechanisms have. If this is right, then contextual mechanisms and wide realizations cannot be assimilated. But, alternatively, it may be that this line of thought relies on an overly-constrained view of mechanisms—as, in effect, I claimed was true of Lyons's (2001) views of systems. Large issues here loom.

4. Conclusion. The concept of realization is, belatedly, receiving the at-

tention it deserves. In this paper I have provided a sampling of some recent views, though I have not tried to be exhaustive. The most obvious (perhaps glaring) omission is recent discussions of multiple realization, such as those of Bechtel and Mundale (1999), Shapiro (2000, 2004), Kim ([1992] 1993, 1998), and Polger (2003). I have tried to suggest some ways in which philosophers who would likely self-identify primarily as philosophers of mind, and those primarily as philosophers of science, have more to say to one another than either might antecedently think. Part of the task that lies ahead is to chart the relationships between a cluster of notions, a cluster to which realization is central. But this can hardly be done solely or even chiefly through a priori conceptual analysis, or a steady diet of simple or unrealistic examples. It is clear that taking seriously the idea that realizations and mechanisms do not exist in an ontological vacuum should direct future thinking here. It is less clear, however, how adequate the metaphor of "hierarchical levels" will prove to be. But that is a topic for another time (Wilson, 2003, 2004, 2005).

REFERENCES

Bechtel, William, and Jennifer Mundale (1999), "Multiple Realizability Revisited: Linking Cognitive and Neural States", *Philosophy of Science* 66:175–207.

Bechtel, William, and Robert C. Richardson (1993), *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research*. Princeton, NJ: Princeton University Press.

Craver, Carl (2001), "Role Functions, Mechanisms, and Hierarchy", *Philosophy of Science* 68: 53–74.

——— (2004) "Dissociable Realization and Kind Splitting", *Philosophy of Science* 71 (Proceedings): 960–971.

Fodor., Jerry A. (1983), *The Modularity of Mind: An Essay on Faculty Psychology*. Cambridge, MA: MIT Press.

Gillett, Carl (2002), "The Dimensions of Realization: A Critique of the Standard View", *Analysis* 62: 316–323.

Glennan, Stuart (1996), "Mechanisms and the Nature of Causation", *Erkenntniss* 44: 49–71.

Kim, Jaegwon ([1992] 1993), "Multiple Realization and the Metaphysics of Reduction", *Philosophy and Phenomenological Research* 52:1–26. Reprinted in his *Supervenience and Mind*. New York: Cambridge University Press, 309–335.

——— (1998), *Mind in a Physical World*. Cambridge, MA: MIT Press.

Lyons, Jack (2001), "Carving the Mind at Its (Not Necessarily Modular) Joints", *British Journal for the Philosophy of Science* 52: 277–302.

Machamer, Peter, Lindley Darden, and Carl F. Craver (2000), "Thinking about Mechanisms", *Philosophy of Science* 67: 1–25.

Polger, Thomas W. (2003), *Natural Minds*. Cambridge, MA: MIT Press.

——— (2004), "Neural Machinery and Realization", *Philosophy of Science* 71 (Proceedings): 997–1006.

Putnam, Hilary ([1960] 1975), "Minds and Machines", in Sidney Hook (ed.), *Dimensions of Mind*. New York: Collier. Reprinted in Hilary Putnam, *Philosophical Papers,* vol. 2, *Mind, Language, and Reality*. Cambridge: Cambridge University Press, 362–385.

Shapiro, Lawrence (2000), "Multiple Realizations", *Journal of Philosophy*, 97:635–654.

——— (2004), *The Mind Incarnate*. Cambridge, MA: The MIT Press.

Shoemaker, Sydney (2001), "Realization and Mental Causation", in Carl Gillett and Barry Loewer (eds.), *Physicalism and its Discontents*. New York: Cambridge University Press.
Wilson, Robert A. (1999), "The Individual in Biology and Psychology", in Valerie Hardcastle (ed.), *Where Biology Meets Psychology: Connections, Conjectures, Constraints*. Cambridge, MA: MIT Press.
——— (2001), "Two Views of Realization", *Philosophical Studies* 104: 1–31.
——— (2003), "Pluralism, Entwinement, and the Levels of Selection", *Philosophy of Science* 70: 531–552.
——— (2004), *Boundaries of the Mind: The Individual in the Fragile Sciences: Cognition.* New York: Cambridge University Press.
——— (2005), *Genes and the Agents of Life: The Individual in the Fragile Sciences: Biology.* New York: Cambridge University Press.
Wimsatt, William (1996), "Aggregativity: Reductive Heuristics for Finding Emergence", *Philosophy of Science* 64 (Proceedings): S372–S384.