Developing the Explanatory Dimensions of Part-Whole Realization

(Forthcoming in Philosophical Studies)

Ronald Endicott
Department of Philosophy & Religious Studies
North Carolina State University
Campus Box 8103, Raleigh, NC 27695
ron_endicott@ncsu.edu

Since the turn of the century philosophers have focused largely on one part-whole theory of realization, and that is Carl Gillett's "dimensioned" theory. So I think it is instructive to examine its details, remove its problems, and use what remains as a platform to develop a plausible part-whole theory of realization. I begin with some desiderata for a theory of realization that its key terms should be defined and that it should be explanatory. I then argue that Gillett's (2002, 2003) original theory violates these conditions because, beyond some basic metaphysical components, its explanatory force rests upon an unspecified "in virtue of" relation. I then examine Gillett's (2007, 2013) later version that appeals instead to theoretical terms tied to "mechanisms." Yet I argue that it too violates the desiderata, since it defines realization for mechanisms in terms of two undefined terms – "implementation" and "grounds" – whose explanatory credentials have not been established. Thus I drop these ideas in favor of an explicit constraint that the parts and properties provide a mechanistic explanation. I also distinguish a special mechanistic theory from a preferred general theory that incorporates other kinds of part-whole explanations, and I compare the latter to a similar idea from Robert Cummins (1983) that has been neglected in recent discussions of realization, namely, his general property analysis rather than his functional analysis. Finally, I defend the preferred theory against possible objections based on issues that arise regarding certain metaphysical demands on a theory of realization versus facts about good scientific explanation.

1. Desiderata for a Theory of Realization.

Hilary Putnam (1960, 1967) popularized the terminology of realization within the philosophical community. Yet, aside from a connection Putnam made with the idea of a one-to-one mapping, most philosophers believe that his use of "realization" was a mere placeholder for some as yet unspecified relation. Putnam was not alone. As Jaegwon Kim put the point: "the term

'realization' was introduced and quickly gained wide currency, chiefly on the basis of computational analogies," with few making an "explicit effort to explain what the realization relation consisted in" (1997, p.186). So *one desideratum for a theory of realization is that it should not use key terms that are undefined*. Call this the "Definition" condition. Of course one cannot be expected to define all terms. What counts as a "key" term depends upon the context of inquiry. For example, if the goal is to understand inter-level realization rather than broader questions about the nature of objects or properties, and if the theory says that "a property *G* realizes a property *F* if and only if *G* and *F* are instantiated by an object *x* and *G* superproduces *F*," then "superproduces" is a key term that should be defined but arguably not "property," "object," or "instantiates."

As well, most philosophers believe that a good theory of realization should provide a physically acceptable explanation for non-fundamental phenomena (Lepore and Loewer 1989; Poland 1994; Kim 1998; Morris 2010). This is why most philosophers do not think that concepts of supervenience are sufficient to express a physically acceptable view, since they are consistent with the brute laws of emergentism (Schiffer 1987; Kim 1990, 1993a; Horgan 1993). This also applies to mereological supervenience, since that doctrine could be true even if micro parts determine macro wholes in a fundamentally unexplained way (Kim 1998, pp.18, 117). So *another desideratum for a theory of realization is that it should provide an adequate explanation for its target phenomena*. Call this the "Explanation" condition. In the next two sections I will argue that Gillett's original theory as well as his later revised theory fail to satisfy the Definition and Explanation conditions.

2. Dimensioned Realization.

Gillett uses "flat" theories as a foil for his own "dimensioned" theory. According to Gillett, flat theories require that the same object *x* possess both realized *F* and realizing *G* properties, and that the causal powers that *F* bestows upon its instances "match" the causal powers that *G* bestows upon its instances (Gillett 2002, pp. 317-18) in a sense that includes causal role (Block 1980; Kim 1998) and subset views (Wilson 1999; Shoemaker 2001). Gillett then argues that flat theories do not represent actual cases of realization in the sciences because they leave out realization by parts, which he illustrates by the case of the diamond lattice whereby properties of

the constituent carbon atoms explain the hardness of a diamond (2002, pp.318-20). He thus offers his dimensioned theory:

> [D] Property/relation instance(s) G_1-G_n realize an instance of a property *F*, in an individual *x*, *if and only if x* has powers that are individuative of an instance of *F* in virtue of the powers contributed by G_1-G_n to *x* or *x*'s constituent(s), but not vice versa (2002, p.322, with a change in variables; also 2003, p.594).

Philosophers have offered a number of criticisms, many of which I will discuss later. But even opponents believe that [D] represents a new turn-of-the-century revolution brought about by philosophers like Gillett who finally addressed the nature of realization directly (Polger 2007, pp.233-34; Kim 2010, p.265; Walter 2010, p.207). Now I applaud Gillett's emphasis upon part-whole dimensions, for I agree that flat theories cannot stand alone. Thus, even when a functional-role theory employs the notion of a structural property that implies parts for its instances, the fact that a structural property occupies a functional role is best explained by a part-whole mechanistic explanation (see Endicott, forthcoming, against role-occupant iterations that do not rest upon whole-to-part decompositions). But Gillett's dimensioned theory requires major development.

I begin with a lesser interpretive problem. [1] Gillett wants to offer an egalitarian definition that covers both flat and dimensioned cases (2002, p.322). Accordingly, the either/or convention governing the use of parentheses around the plural ending indicates that "property/relation instance(s) G_1-G_n" on the left-hand side of the biconditional in [D] should be taken to refer to either a single instance of the realizing kind described by a flat theory or a plurality of part instances of the dimensioned kind emphasized by Gillett. But if the same terms "G_1-G_n" are

[1] Another lesser problem is an ambiguity between properties and property instances. Thus, on the left-hand side of the biconditional, the wording of "an instance of a property *F*" makes it clear that "*F*" stands for a *property*, yet the absence of the preposition in "property/relation instance(s) G_1-G_n" seems to indicate that the terms "G_1-G_n" stand for *instances*. See also the shift between properties and instances when Gillett describes a flat theory's structure "COMBO" (2002, p.320). But this ambiguity is ultimately harmless, since realization can be defined for either category (see Endicott 2010).

expanded in the same way on the right-hand side of the biconditional, then the theory is compatible with the view that the entire explanatory burden could be carried by the single flat realizer (disjunctions can be made true by just one of the disjuncts). That result seems contrary to the spirit of a part-whole theory. That result also seems contrary to Gillett's argument that a flat theory's role-occupying or subset-inclusive structural property COMBO must have its instances decomposed in a whole-to-part way (2002, p.320), since by that argument any flat claim within [D] should be underwritten by a part-whole analysis. So this suggests a different interpretation of [D] that takes the terms "G_1-G_n" on the right-hand side of the biconditional to refer solely to part properties. [2] Of course a simpler alternative is to offer a pure dimensioned theory shorn of flat elements. Then, if an egalitarian compromise is desired, one may say that realization fits either a flat definition or the pure dimensioned definition and leave it at that. Indeed, if one wants to know what theoretical advance [D] makes over older ideas, then one should set aside the traditional flat ideas that Gillett wants to improve upon. Hence Gillett's theory has four remaining elements: (i) property instantiation; (ii) a metaphysics of causal powers; (iii) part-whole determination; and (iv) some *in virtue of* relation.

Now my main argument against [D] is that Gillett has merely added an unspecified and hence unexplanatory *in virtue of* relation to some familiar dry goods in metaphysics that most would acknowledge to be insufficiently explanatory (I will examine Gillett's later theory that replaces the "in virtue of" with other notions in the next section). So, taking each element of [D] in turn, (i) Gillett understands realization in terms of properties and relations being instantiated. But philosophers commonly used "realization" and "instantiation" in the same context and often interchangeably (Searle 1980, pp.418-23; Pylyshyn 1980, p. 29; Horgan 1984, p.460). Moreover, an appeal to instantiation carries no serious explanatory weight in the present context, since emergentists also believed that their properties and relations were instantiated. (ii) Gillett also frames his theory in terms of a metaphysics of causal powers. But that is a general metaphysical idea that has been popular since Sydney Shoemaker's (1980) causal theory of properties, and it

---

[2] Cf. Ronald Endicott's (2011, p.196) synthesis of flat functional-role and dimensioned views that defines functional realization in terms of a three-place relation whereby an object's occupier G_i realizes its functional F in virtue of properties G_1-G_n possessed by its parts. This conjoins rather than disjoins the two ideas.

too is compatible with emergentism as long as the whole has causal powers that are unexplained by the causal powers of its parts.

(iii) Gillett embraces part-whole determination. He does not explicitly state the point about determination in [D], but it is implied. For example, Gillett wants to subsume flat views under [D]. Yet they imply determination. [3] More central to the dimensioned theory, Gillett refers to "constituent(s)" in the definition, yet he says elsewhere that the pertinent compositional relations included within the scope of his theory are all forms of "synchronic noncausal determination" (Gillett 2007, p.200). Indeed, both Kenneth Aizawa and Gillett say plainly that "realization is a transitive ontological determination relation" (Aizawa and Gillett 2009, p.195). But part-whole determination is just mereological supervenience, a view made popular by Kim and conceded to be insufficiently explanatory (Kim 1993a, 1998). Finally, (v) Gillett appeals to an *in virtue of* relation. He says that "*x* has powers that are individuative of an instance of *F* in virtue of the powers contributed by G_1-G_n to *x* or *x*'s constituent(s)" (2002, p.322, again with a change in variables; also 2003, p.594). Yet that too is a familiar theme. As Kim said about the shortcomings of supervenience:

> Much of the philosophical interest that supervenience has elicited lies in the hope that it is a relation of dependency … Often it is thought, or claimed, that a thing has a supervenient property *because*, or *in virtue of the fact that*, it has the corresponding base property, or that its having the relevant base property *explains* why it has the supervenient property … Clearly property covariation [mere determination by supervenience] by itself does not warrant the use of "because," "in virtue of," etc., in describing the relationship any more than it warrants the attribution of dependence (1990, p.147; see also Heil 1992, p.65).

[3] E.g., the flat causal-role functionalist theory of realization implies that the instantiation of a realizer property *G* determines the instantiation of the realized *F*, for if it is a matter of law that *G* stands in causal relations *R*, and if *F* is defined as the property possessed by an object when it has some property that stands in *R*, then it will be a matter of law that whenever an object has *G* it has *F* (see Tye 1995, pp.41, 47-48).

So, putting aside the flat elements in [D], Gillett's theory is merely instantiated mereological supervenience expressed with a metaphysics of causal powers plus some *in virtue of* relation that Kim and many others said was missing from supervenience. But the point is not just that Gillett's theory represents a lack of theoretical progress. Kim (1990) cashed in his talk of "because" and "in virtue of" by appealing to a functional-role explanation, and he subsequently (1998) defined realization explicitly in terms of a functional-role theory. In contrast, Gillett's unspecified "in virtue of" is the key difference that distinguishes his theory from a familiar and explanatorily deficient set of ideas. As a result, [D] does not satisfy the two desiderata I presented for a theory of realization. It violates the Definition condition because it leaves its key theoretical term undefined. And it violates the Explanation condition because its key undefined term does not raise the expressed dimensioned ideas to the level of an explanatory theory. Certainly "in virtue of" does not indicate any relevant features of an explanation (it is like offering a theory of causation by saying that "an effect *y* exists *because of x*" without indicating how "because of" should be understood, say, in terms of a counterfactual analysis, or ideas about manipulability, or mechanisms, or a transfer of energy, and so on). Now, in response, one might think my criticism can be blunted by Gillett's clarification regarding his intentions in providing [D]. He says:

> First, I offer it as an account of the notion of realization implicit in scientific theorizing, and not any folk concept. Second, I take realization to be a basic metaphysical notion whose nature is intimately bound up with a family of notions. In particular, I ultimately believe that realization and constitution are interdefined and I thus offer my definition as a nonreductive, but I hope illuminating, account of its connection to other basic notions (2002, p.322, fn.8).

But these remarks do not help. Beginning with the second, suppose realization's *in virtue of* concept is a basic metaphysical notion that is interdefined with a basic concept of constitution. If so, Gillett has offered nothing more than a view Kim briefly entertained in the early 1990s before he settled on a functional-role approach. Specifically, after rehearsing the problems for supervenience, and after noting that ethical notions of same-subject supervenience can be explained in assorted ways, Kim turned to mereological supervenience as a non-ethical, objective

relation in the world and postulated a fundamental form of dependence: "This supervenience relation does not seem to be explainable in terms of any of the candidate explanations we have just canvassed for valuational supervenience. It seems likely that mereological supervenience represents a metaphysically fundamental, *sui generis* form of dependence" (1993a, p.166). I see little difference between mereological supervenience, a metaphysics of causal powers, and a *sui generis* form of dependence, versus an instantiated mereological supervenience, a metaphysics of causal powers, plus some metaphysically primitive *in virtue of* relation. Moreover, put aside the component *in virtue of* concept and consider the suggested nonreductive link between the containing concept of realization and a basic concept of constitution. But constitution is likewise intimately bound up with mereological supervenience. Consequently, if the link to a basic concept of constitution was insufficient to transform the idea of mereological supervenience plus causal powers into a viable theory, that same link to constitution should be insufficient to transform the idea of an instantiated mereological supervenience, causal powers, plus some as yet unspecified *in virtue of* relation into a viable theory.

Finally, consider Gillett's first clarification that his concept of realization is something implicit in scientific theories, not some folk notion. Very well, the scientific theories Gillett has in mind should throw some light on what he intends (I will discuss his examples later). But the trouble is that, beyond the aforementioned generic ideas, Gillett's definition does not express anything of explanatory value about the scientific theories in question, or the explanations provided by them, and thus it fails as an account of realization that those explanations supposedly imply. For example, philosophers distinguish many different kinds of part-whole explanations in the sciences, including explanations of *historical processes* versus *aggregates* versus *morphological compositions* versus *systematic mechanisms* (Levins 1970; Haugeland 1978; Cummins 1983; Wimsatt 1986, 2006; Bechtel and Richardson 1993; Machamer, Darden, and Craver 2000; Winther 2011). I will have more to say about the differences later. But Gillett's "in virtue of" does not express what is distinctive about any part-whole explanation in the sciences, just like invoking the common-language "because of" does not expresses what is distinctive about any causal explanation in the sciences. One must articulate the relevant features of the desired range of cases that will both identify the kind of scientific explanations at issue

and distinguish them from others, and then represent those features in a philosophical definition or analysis. [4]

I suspect that most philosophers have looked past this issue because they were more interested in the contrast between multiple-subject dimensioned theories versus single-subject flat theories. Indeed, the fact that Gillett presented his dimensioned theory as an explicit contrast to flat theories effectively drew attention to the matter of dimensioned parts versus flat wholes rather than any differences or deficiencies regarding Gillett's particular part-whole theory versus others, say, Kim's (1993a) mereological supervenience with an added primitive dependence, or Cummins' (1983) property instantiation theory, of which I will say more later. But one philosopher did briefly raise a problem about Gillett's use of "in virtue of." Thomas Polger, Gillett's main critic, says in a footnote of a paper devoted to a different criticism that [D] is "less than perspicuous" and offers a streamlined definition that "eliminates the 'in virtue of' locution": "Property/relation instance(s) G_1-G_n realize an instance of a property F, in an individual x, if and only if G_1-G_n are properties of x or x's constituent(s) and G_1-G_n contribute the powers that are individuative of an instance of F to x but not vice versa" (2007, pp.237-38, fn.8, with a change in variables). Polger then says that "even with this adjustment, it is hard to see how the account explains realization" (loc. cit.), and he briefly goes on in the same footnote to state that the mere fact that parts contribute powers to a whole does not explain how this happens. I agree. But I have not viewed Gillett's use of "in virtue of" merely as a point of unclarity that should be removed so that a more perspicuous formulation of his theory may be assessed. I have stressed that it is unfortunately the central idea that serves to distinguish Gillett's theory from some old dry goods in metaphysics that are inadequate for explanation. I have also offered a more extensive critique that takes into account Gillett's clarifications, arguing that links to fundamental metaphysical notions such as constitution as well as illustrations of scientific explanations do not obviate the need to replace "in virtue of" with a theoretically useful concept that provides some information about the kinds of part-whole explanations at issue.

---

[4] Aizawa and Gillett recently refer to [D] as a "thumbnail sketch" (2009, p.186, fn.9). But providing a sketch does not preclude the obligation to provide enough information in the definition to identify the pertinent kinds of part-whole explanation.

3. Dimensioned Realization for Mechanisms.

In a later work (2007) Gillett develops his theory. This new theory deserves a close look not only because most philosophers have focused upon the original [D], but also because Gillett no longer uses the unspecified "in virtue of." Gillett starts with a definition of "comprising powers":

> [C] (Comprising) Powers C_1-C_n, had by individuals y_1-y_n (or individual x), comprise the power C_f, had by individual x under background condition B, if and only if the mechanisms grounded by the triggering and manifestation of powers C_1-C_n, under triggering conditions Bt_1-Bt_n and background condition B, would together implement the mechanisms grounded by the triggering and manifestation of C_f, under triggering conditions Bt_1-Bt_n and background condition B, but not vice versa (2007, p.202, with variables changed; the same definition is repeated in 2013, p.324, fn.20). [5]

Gillett then defines realization on the model of [D] with a clause about such comprising powers:

> [Dm] (Realization) Property instances G_1-G_n, in individuals y_1-y_n (or individual x), realize a property instance F, in individual x under background conditions B, if and only if the powers contributed by G_1-G_n to y_1-y_n (or x), which are constituents/parts of x, together comprise the powers individuative of F, in x under B, but not vice versa (2007, p.202, with variables changed; the same definition is repeated in 2013, p.323).

Consonant with the larger issue Gillett addresses regarding compositional reduction in the sciences, I read [Dm] as a pure part-whole theory rather than a disjunction of flat and dimensioned ideas. Accordingly, Gillett dropped the set of parentheses around the plural ending of "instances" on the left-hand side of the biconditional which allowed the realizer in [D] to be a single instance of the kind described by a flat theory. Instead, the only disjunction he employs in

[5] The reference to triggering conditions in [C] creates a problem for [Dm], since the latter does not mention them. In any case, I will count them in [Dm]'s background conditions.

the *definiendum* of [Dm] concerns the location of the property instances G_1-G_n, either "in individuals y_1-y_n (or individual x)," where I assume the latter is implied by a pertinent interpretation of the part-whole relation (in the sense of spatial location, if instances G_1-G_n are "in" parts y_1-y_n, and those parts are "in" the whole x, then the instances G_1-G_n are "in" the whole x). [6] But the most important change is that Gillett replaced the "in virtue of" with technical terms about comprising powers in [Dm] that are tied to "mechanisms" in [C]. As a result, Gillett's new theory [Dm] contains (i) property instantiation; (ii) a metaphysics of causal powers; (iii) part-whole determination (relative to background conditions); and the claim that (iv^m) mechanisms grounded by the triggering and manifestation of powers C_1-C_n together implement the mechanisms grounded by the triggering and manifestation of the target power C_f. Yet Gillett's modified theory has serious problems.

Gillett says in [C] that mechanisms grounded by powers C_1-C_n associated with the part properties "implement" the mechanisms grounded by the power C_f associated with the target property of the whole. But once again Gillett leaves this key term undefined. Hence, because [C] provides the analysis of the comprising powers cited in [Dm], Gillett ultimately defines "realization" by means of an undefined "implementation." This is at best unhelpful, since "implementation" stands equally in need of explication. This is at worst circular, since "implementation" is often used in the place of "realization," both among philosophers (Searle 1990, p.26; Chalmers 1996, p.309) and computer scientists (von Neumann 1956, p.43; McDermott 1976, p.144). Moreover, Gillett cannot assume any standard interpretation of "implementation" in the literature, since philosophers and computer scientists typically treat *implementation* as a one-to-one mapping between certain abstractly conceived items like machine tables or descriptions and the concrete states in a physical machine, or that same mapping plus the appropriate counterfactually supporting causal structure in the physical machine (see Chalmers 1996; Rapaport 1999). In contrast, a part-whole mechanistic explanation requires a one-to-many relation between a concrete whole and its concrete parts, such as a brain

[6] Also, there is but one disjunction in the *definiens* about what receives the powers from the parts, namely, the "powers [are] contributed by G_1-G_n to y_1-y_n (or x)," and I assume this only means that the multiple property instances contribute powers either directly to the parts y_1-y_n or indirectly to the whole x by their direct contributions to the parts.

system and its neural parts. [7]

A similar argument could be made regarding Gillett's reference in [C] to mechanisms being "grounded" by the triggering and manifestation of powers, since Gillett leaves that term undefined too. Yet *grounding* is another way to think about inter-level relations, and it is often taken to be a metaphysical primitive that would be ill-suited for the kind of explanatory project that is expected from a theory of realization (see Jessica Wilson 2014). [8] So, given that ideas about mere parts and wholes and causal powers are insufficiently explanatory, then the addition of *two* undefined inter-level terms will not yield an explanatory theory. [Dm] does not satisfy the Definition condition, since it leaves key theoretical terms undefined. And [Dm] does not satisfy the Explanation condition, since its undefined ideas fail to express any relevant features that explain the powers of a whole by the powers of the parts.

Now Gillett does not mention the issue of circularity regarding "implementation" or "grounds" directly, but he briefly states in a footnote that some readers may be concerned that the "interdefined nature" of [C] and [Dm] "may raise problems of circularity," and he then says:

---

[7] E.g., in the case of neurotransmission, the explanation proceeds by breaking down the signaling function of a neuron into various processes involving certain parts, including the reception of neurotransmitter molecules, the opening of ion channels in a neuron's membrane, and the entrance of positively charged ion atoms through those channels into the cell body, all of which are crucial to the cell's depolarization (for more details, see Doyle, et. al. 1998; Jensen, et. al. 2012).

[8] In a later paper Gillett (2013, p.312) says that a "process" is an individual manifesting a power that results in an effect, and he says that an individual "grounds" that process when its powers so result in an effect (2013, ibid.). This seems to be a different claim than what is made in [C] (2007). In [C] (2007) the triggering and manifestation of powers ground the individual mechanism. But in (2013) the individual mechanism grounds the triggering and manifestation of powers (presumably because the individual is a part of that larger process). Either way, the grounding remains undefined.

> In response, it should be noted that I am offering an account in the metaphysics of science that simply seeks to articulate the nature of compositional concepts in the sciences, rather than trying to replace these scientific notions with other concepts. Furthermore, our basic concepts in some area are often inextricably intertwined and my account merely reflects this feature in the scientific case we have considered. For we have seen that concrete scientific cases posit “packages” of compositional relations between powers, properties, individuals, and mechanisms (2007, p.203, fn.13).

His remark about articulating "compositional concepts in the sciences" and his remark that such basic concepts are "inextricably intertwined" are very much like the two clarifications Gillett made about [D] (2002, p.322, fn.8) that I discussed earlier regarding scientific theories and a postulated interdefined link between realization and constitution. But there are two differences worth noting. First, because Gillett makes a direct appeal to "mechanisms" in [C], which he did not do in [D], [Dm]'s "implementation" is explicitly tied to mechanisms within the definition. Second, Gillett introduces even more nonreductive interdefined links with basic notions – not just between realization and constitution as before – but now a larger package of relations that includes "constitution for individuals," "comprising between powers," "implementation for processes," and "realization between properties" (2007, p.196, fn.6). But these clarifications do not help.

To begin, even though Gillett refers to "mechanisms" in [C], and thus by implication in [Dm], *the definition does not actually state that realization occurs because the mechanisms are subject to a mechanistic explanation.* Rather, Gillett utilizes the concepts already mentioned, saying that mechanisms grounded by powers C_1-C_n should together "implement" the mechanisms grounded by C_f. That will imply a theory of realization based upon mechanistic explanation only if one defines "implementation" in terms of a mechanistic explanation, which Gillett does not do. Of course I believe Gillett wants [Dm] to express a part-whole mechanistic explanation, once the schema is appropriately filled in. He uses the term "mechanistic explanation," and he cites a number of familiar works that both promote and analyze mechanistic explanation (2007, p.194, fn.7). And of course mechanisms are subject to mechanistic explanation. But the problem is that Gillett's theory does not *say* that realization is a form of

mechanistic explanation. Instead, and again, its central inter-level ideas are the explanatorily inadequate generic notions of parts and wholes and causal powers plus the newly introduced but undefined ideas about implementation and grounds.

Also, in case one thinks that my point is mere "nitpicking" and that Gillett's reference to mechanisms in [C] should suffice, recall that Putnam too spoke about mechanisms – paradigm computing machines. Yet when it came to formulating a theory of realization or implementation for those machines, Putnam spoke of mappings and otherwise left the substantive theory of realization wide open. Gillett has done the same thing with his modified theory of realization, only he speaks in terms of implementation and grounds. Turning then to Gillett's clarification *via* a larger package of relations, the appeal to "constitution for individuals," "comprising between powers," "implementation for processes," and "realization between properties" (and grounding for mechanisms?) only widens the circle of ideas but does not break it. For the fact remains that "realization" rests upon key undefined ideas which ensure that [Dm] fails to satisfy the Definition and Explanation conditions. [9]

Finally, I want to compare my argument to the only criticism in the literature specifically directed at Gillett's modified theory [Dm]. Polger (2010) cites Gillett's (2007) theory, and he makes three claims: (a) it is merely a "descriptive" theory that says when or that an ontological dependence relation holds, not an "explanatory" theory that helps one to understand why or how that dependence occurs (2010, pp.200-202); (b) it is problematic because, unlike the authors he cites, Gillett's theory is insensitive to the difference between aggregates and mechanisms (2010, pp. 204-7); and (c) given these problems, one should prefer a flat functional-role theory (2010, pp.199, 210), although Polger concedes that a dimensioned approach provides an apparently a

[9] Gillett adds in a more recent work that the parts in a constitution relation have "spatio-temporal, powerful, and/or productive" relations to each other (2013, p.311). But Gillett does not define the kind of "spatio-temporal relations" in question or indicate how they would either exclude unexplained emergent cases or capture the desired range of scientific explanations. Also, by "powerful" Gillett (2013, p.312) only means the notion of causal powers introduced by Shoemaker. And by "productive" Gillett (2013, p.312) only means the power of an individual to be triggered and manifested to produce an effect – all of which are ideas already expressed in [C] and [Dm].

more plausible account of "vertical" or part-whole constitutive mechanistic explanation (2010, p.199-200). Now I agree with Polger on (a), although my reasons for rejecting the explanatory adequacy of [Dm] are different than his. Briefly, Polger interprets [Dm] like Gillett's original egalitarian theory [D] that applies when the individuals are mereologically related and when they are not (Polger 2010, p.200). He then argues that [Dm] does not indicate which, among the available options – identity or composition via some spatially overlapping matter or a proper-part-to-whole relation – is the relation that is explanatorily relevant (2010, pp.200-2). [10] I read [Dm] differently as a pure proper-part-to-whole theory, as I stated previously. But, regardless, Polger does not mention anything about Gillett's reliance upon the undefined notion of implementation that provides the basis for my criticism that the theory violates the Definition and Explanation conditions. Our arguments are quite different.

Regarding (b), whereas I agree that [Dm] is insensitive to the distinction between aggregates and mechanisms, yet contrary to Polger I think the fact that Gillett means something much broader by "mechanistic explanation" than those he cites within the recent mechanistic movement within philosophy is actually a point in favor of Gillett's view. As I will argue in the next section, if one wants a general theory of realization that extends beyond the special sciences like biology and cognitive science, then one cannot be restricted to the mechanisms described in those special sciences. Finally, regarding (c), rather than fall back on a flat functional-role view because of problems with [Dm], I will construct a better part-whole dimensioned theory in the next section. Moreover, although I do not have the space to develop the argument here, I also think this part-whole theory provides a needed supplement for the kind of flat functional-role theory that Polger prefers (see Endicott, forthcoming).

---

[10] Polger (2010, p.2002) also seems to tie this point to Shapiro's (2004) argument that, for purposes of functional analysis, one should discriminate among the parts and properties that combine to determine a functional property. However, Shapiro's argument applies even after one has set aside the options of identity and spatially-overlapping constitution and settled upon a relation of proper parts to whole. That is, among an object's proper parts, some will be relevant to a functional analysis and others not.

4. Realization via Special Mechanisms and General Structures

Although Gillett's dimensioned theories [D] and [Dm] have problems, I believe his reference to mechanisms and his many discussions of mechanistic explanation point in the right direction. Specifically, I suggest that a better part-whole theory of realization can be formulated if one drops the undefined terms and incorporates an explicit clause about mechanistic explanation. I think one should also resist reading Gillett's system of "constitution for individuals," "comprising between powers," and "realization between properties" in a metaphysically extravagant way that implies substantively different relations in the world. As a good Aristotelian, I think one may understand the relations between properties and powers by the relations between the individuals that possess them. I thus recommend that one drop Gillett's [C] and then revise [Dm] along the lines suggested:

> [PWme] Properties/relations G_1-G_n instantiated by an individual *x's* proper parts y_1-y_n realize a property/relation *F* instantiated by that individual *x*, under background conditions *B*, if and only if, *x* instantiates *F* and *x's* proper parts y_1-y_n instantiate G_1-G_n; it is necessary that if y_1-y_n are proper parts of *x*, and y_1-y_n have G_1-G_n, and *B* holds, then *x* has *F*; and y_1-y_n having G_1-G_n, along with their causal powers, provide a mechanistic explanation for *x* having *F*, along with its causal powers, under *B*, but not vice versa.

Unlike Gillett's [D], [PWme] is a pure part-whole theory. It is also simpler than Gillett's [D] and [Dm], since it is framed in terms of properties that are instantiated by individuals, leaving talk of property instances, or similar items such as event structures, tropes, and states of affairs to one side (such things may exist when an object instantiates a property, but there is no need to refer to them). But the important difference is that [PWme] contains an explicit reference to mechanistic explanation. So [PWme]'s main elements are: (i) property instantiation, (ii) a metaphysics of causal powers, (iii) part-whole determination (relative to background conditions), and now the further constraint that (iv^{me}) the parts and their properties and relations provide a mechanistic explanation for the target property of the whole.

Now this kind of theory is not unprecedented. There are flat mechanistic theories of realization, for example, functional-role theories that speak of the occupier as the mechanism for

the role-defined property (Kim 1993b; Tye 1995). But there are also part-whole mechanistic theories of realization. Thus, Robert Cummins' (1975) offered a part-whole functional analysis, of which mechanistic explanation is a more specific species (Craver 2001 develops Cummins' functional analysis into a current and highly influential account of mechanistic explanation). I will have more to say about Cummins' views shortly. As well, Laurence Shapiro (2004) cites Cummins' functional analysis as a constraint on what may count as a realization, thus implying a theory like [PWme]. Also, Matthew Haug (2010) recently describes something like [PWme] by speaking of realization in terms of mechanistic explanation, and by citing (2010, p.320) authors who promote notions of mechanistic explanation that are tailored to functionally organized systems in biology and cognitive sciences (Bechtel and Richardson 1993; Machamer, Darden, and Craver 2000; Craver 2007). Nevertheless, different philosophers mean different things by "mechanistic explanation," which leads to different theories of part-whole mechanistic realization. This key term must be explained.

Thus, most contemporary philosophers of science understand mechanistic explanation in a special way for functionally organized biological, engineering, and cognitive systems. There are multiple lines of influence for this view, but one traces back to Richard Levins' (1970) distinction between "aggregate," "composed," and "evolved" systems. According to Levins, aggregate systems are such that "the properties of the whole are statistics of the properties of parts" (1970, p.76). So the mass of a pile of sand would be a property of an aggregate, since it is explained by a simple summation principle applied to the mass of each part. But, according to Levins, composed systems require more than simple statistical methods, even though "the properties of the parts can be completely specified by study in isolation," as illustrated by an engineering circuit (1970, p.77). Finally, Levins says that evolved systems are such that the parts are not "obviously separable" (1970, p.77), by which he means that, unlike mere composites, their functions can only be specified by relations to other parts within the system. [11] Inspired by

[11] Likewise, William Bechtel and Robert Richardson (1993, p.26) distinguish between *aggregate* systems for whom intersubstitution of parts holds, *component* systems for whom intersubstitution fails but the functional behavior of a part is intrinsically determined, and *integrative* systems for whom intersubstitution fails but the functional behavior of a part is determined by a broader systemic organization, such as feedback among subsystem parts. I also think that John

Levins, William Wimsatt (1986, pp.260-68) then offered four criteria that define aggregativity *vis-à-vis* a system property targeted for explanation by the parts, and he proposed that the degree to which a case fails to meet these criteria provides an opposing classification of a system as a mechanism. I will mention two criteria. As Wimsatt would later formulate them:

> (InterSubstitution). Invariance of the system property under operations rearranging the parts in the system or interchanging any number of parts with a corresponding numbers of parts from a relevant equivalence class of parts …
> (Linearity). There are no Cooperative or Inhibitory interactions among the parts of the system which affect this property (2006, p.676).

So the mass of a pile of sand is a system property of an aggregate because one grain can be interchanged with another without affecting the overall mass of the pile, and also because there are no cooperative or inhibitory interactions between the grains of sand. In contrast, familiar mechanisms like computing machines and assorted neural systems fail to meet these conditions. Thus, neurotransmission is not subject to intersubstitution of parts, for if the excitatory neurotransmitter molecules in the dendrites are switched with the ion channel molecules in the cell body there will be no neurotransmission (see again fn. 7). Also the targeted function of a nueron does not exhibit simple linearity, as Wimsatt defines it, since there are both excitatory and inhibitory interactions, depending upon neighboring neurons and what kind of neurotransmitters they release. Mechanistic explanations must therefore utilize principles that apply to such functionally organized systems. And mechanisms display other features. For example, as Machamer, Darden, and Craver (2000, p.11) describe them, mechanisms involve a functional *process*, in the case of neurotransmission, how the parts of the neural system work from a start-up condition whereby a pre-synaptic neuron releases neurotransmitter molecules, an

---

Haugeland's (1978) distinction between "morphological" versus "systematic" explanations is roughly equivalent to the latter two cases, i.e., composed systems (e.g., explaining how a cup holds coffee and how a fiber-optics bundle preserves the data it received) and then the functionally organized systems (e.g., explaining how an automobile engine works and how the brain does its information processing).

intermediate stage whereby a post-synaptic cell receives the neurotransmitters, to an end-state condition whereby the post-synaptic neuron depolarizes and thus transmits a signal. They also involve *multiple-level, nested hierarchies*, which they illustrate with the same case of neurotransmission: "the activation of the sodium channel is a component of the mechanism of depolarization, which is a component of the mechanism of chemical neurotransmission, which is a component of most higher-level mechanisms in the central nervous system" (2000, p.13). And they observe that explanations of such mechanisms typically bottom out in the lowest level of interest for a given scientist, research group, or field (loc. cit.). Let "mechanism" thus mean a functionally organized, multiple-level, nested hierarchical system with cooperative parts that cannot be substituted for one another.

Of course not every case is either a pure aggregate or a pure mechanism, which is why Levins spoke of a middle ground for "composites" and why Wimsatt spoke about forms of aggregativity and degrees of satisfaction for the criteria. One may thus count organizational complexity as a matter of degree, conceiving of each case on a continuum with pure aggregates as a limiting case on one end, assorted composites in the middle, and paradigm systematic mechanisms as a limiting case at the other end. One may also adopt the same convention for their explanations. Thus, by this scheme, "mechanistic explanation" contrasts with other part-whole explanations that target less functionally organized systems. Indeed, this division has now become entrenched within the philosophy of science.

But not everyone equates mechanistic explanation with the explanation of functionally organized systems, as described above. For example, Gillett uses "mechanism" very broadly to cover any case where there is a composite object whose causal powers are explained by the powers of its parts. Thus, in the same paper where Gillett (2007) introduces [Dm], he offers the definition as a way to make sense of a broad range of "compositional" cases in the sciences, not just those involving paradigm mechanisms like computing machines and machine-like biological systems. In accordance with this broad usage, Aizawa and Gillett (2009, p.183) reject competing accounts of realization if they fail to acknowledge "all the kinds of scientific explanations that reveal 'causally relevant properties.'" Yet aggregates are compositional cases in the sciences, and their mass is surely a causally relevant property. The same is true for assorted other properties of composites, such as "density, refractive index, conductance, etc." (Aizawa and Gillett 2009,

p.191). Indeed, Gillett's oft-used example of the diamond lattice (Gillett 2002; Aizawa and Gillet 2009) is not a mechanism in the special sense described above.

Recall that Polger (2010) views this as a problem. But Gillett is not wrong to speak in this fashion. Philosophers and scientists have spoken for centuries about a "mechanistic view of the universe," not just a mechanistic view of neural systems. They have also spoken about "mechanics" as a branch of physics, not biology. Émile Durkheim (1893) even spoke of "mechanistic" social groups with exactly the opposite meaning from what is intended by the recent mechanistic movement in biology and cognitive science – for him the "organic," not the "mechanistic," displays an interdependence of constituent members. But however one wants to mark the distinctions, some distinctions should be made. Thus I will adopt the convention that distinguishes "mechanistic explanation" in a special sense that is confined to highly organized functional systems from "compositional explanations" and "aggregate explanations" that extend to less functionally organized systems, pace the Levins-Wimsatt scheme. I will also interpret [PWme] as a special theory for such mechanisms. Hence one may now consider a more general theory:

> [PWacme] Properties G_1-G_n instantiated by individual *x's* proper parts y_1-y_n realize a property F instantiated by that individual x, under background conditions B, if and only if, x instantiates F and *x's* proper parts y_1-y_n instantiate G_1-G_n; it is necessary that if y_1-y_n are proper parts of x, and y_1-y_n have properties G_1-G_n, and B holds, then x has F; and y_1-y_n having G_1-G_n, along with their causal powers, provide something within the spectrum from aggregate to composite to mechanistic explanation for x having F, along with its causal powers, under B, but not vice versa.

So [PWacme] contains (i) property instantiation, (ii) a metaphysics of causal powers, (iii) part-whole determination (relative to background conditions), and now a more general condition (iv^{acme}) that appeals to aggregate, or composite, or mechanistic explanations. [PWacme] thus meets the two desiderata for a theory of realization I introduced earlier. It does not resort to key undefined terms like "in virtue of" or "implements" to supplement its core metaphysical components. And it expresses the fairly well understood concepts of part-whole

explanation in the sciences covered by the Levins-Wimsatt scheme of classification. I also prefer [PWacme] over a specialized theory like [PWme] for the simple reason of generality. [PWacme] is defined to include [PWme]'s special mechanistic explanations, and hence nothing is lost by adopting [PWacme] and much is gained by incorporating other part-whole explanations. Indeed, given that highly functionally organized systems decompose into simpler systems, mechanistic explanations are always underwritten by compositional and aggregate explanations. [12] This provides yet another reason to prefer the general [PWacme] over the special [PWme].
And of course, in light of my previous criticism, I prefer [PWacme] over Gillett's [Dm]. Even though Gillett's broad view of mechanistic explanation covers a similarly broad range of cases, [PWacme] alone is explicitly defined in terms of the said types of explanation and it does not invoke key undefined concepts. [PWacme] is thus a mixed theory that has the explanatory virtues of mechanistic theories as well as the larger scope desired by Gillett.

Finally, I should point out that the result is much like a part of Cummins' (1983) view of realization that has been neglected in recent discussions of realization – not his functional analysis but his more general property theory. To wit, Cummins says that *property theories* explain what it is for a system to have a property (rather than why a system changes from one state to another). In the case of dispositions, they do this by analyzing the system into simpler dispositions. They are thus whole-to-part decompositional theories. [13] Moreover, as Cummins conceives it, a complete explanation by this kind of theory involves two stages: an *analysis* of the property and then an account of how the property is *instantiated* (1983, 31). This too is decompositional. So a *property instantiation theory* explains how a property of a system *S* is

---

[12] Interestingly, it might not be true that compositional explanations are always underwritten by simple aggregate explanations, e.g., if quantum-entangled states are not determined by the intrinsic physical properties of the individual particles but rather arise non-locally, exemplifying a kind of non-separability (see Maudlin 1998).

[13] Cummins says that property theories fall under the general "analytic strategy" exhibited in the sciences (1983, p.17). Compare how Nancy Cartwright summarizes the "analytic method" in physics: "to understand what happens in the world, we take things apart into their fundamental pieces; to control a situation we reassemble the pieces, we reorder them so they will work together to make things happen as we will" (1999, p.83).

instantiated by means of "the properties of *S*'s components and their mode of organization" (1983, p.15). In short, that is a part-whole dimensioned theory of realization.

Now, what is important for present concerns, Cummins distinguishes three kinds of property theory. There is a general "property analysis" under which Cummins includes such things as Einstein's explanation of the photoelectric effect whereby metals have a disposition to emit electrons when they absorb light as well as the explanation of Archimedes' Principle that specifies the disposition of water to exert an upward buoyant force on a submerged body (1983, pp.19-21). There is also Cummins' well-known "functional analysis" as a special case of this general property analysis when the property is a disposition or capacity and when that capacity is understood functionally by its role within a containing system (a function, he adds, that can be specified by a program or a flow chart (1983, p.28)). [14] Then there is a more special kind of functional analysis, which Cummins calls an "interpretive analysis," that views a more narrow range of functionally organized systems in terms of a semantic interpretation of their supposed symbols, pace the symbol system hypothesis for computing machines (1983, pp.34ff.).

So consider the general property theory, including both the analysis and the instantiation theory. Cummins acknowledges that there are instantiation and composition laws (1983, pp.7, 17-18), although he rightly emphasizes that the force of an explanation *via* a property instantiation theory derives from the parts and their mode of organization rather than the mere fact of a covering law or part-whole determination. So, taking all this together, Cummins offers a general part-whole property instantiation theory [GPI] that contains (i) property instantiation, (ii) a metaphysics of capacities or dispositions, (iii) part-whole determination or instantiation laws, and the condition that (iv^{pi}) the parts provide an explanation of a target property of the whole. If one includes the special functional and interpretational explanations under this general property instantiation theory, the result is something very much like [PWacme].

There are differences. For example, the inclusive [GPI] incorporates a ternary distinction between property, functional, and interpretive analysis. [PWacme] is informed by a ternary distinction between aggregate, composite, and mechanistic explanation. They are not equivalent.

---

[14] Although Cummins presents his functional analysis as a way to understand the function of a part in terms of a containing system (e.g., the heart *vis-à-vis* the circulatory system), it is also a way to thereby understand a function of the whole in terms of the functions of the parts.

[PWacme] is more detailed at the low end of the spectrum by distinguishing aggregates from other composites, whereas [GPI] is more detailed at the high end of the spectrum by distinguishing symbol systems from other functional systems. There is also a substantive difference, given that Cummins' (1983) interpretive analysis reflects a kind of instrumentalism for special science explanations that appeal to encoded symbols that I do not endorse and that I did not include in my gloss on mechanistic explanation (Cummins moved to a more realism-compatible view in 1996). Nonetheless, the theories are much in the same spirit by explicitly tying realization/instantiation to part-whole explanations in the sciences.

Of course there are other ways to categorize the vast array of existing part-whole explanations in the sciences. For example, within the special range of mechanistic explanations one might distinguish between mere functionally organized symbol systems and those that are program-controlled (see Piccinini 2010). My point in offering [PWacme], with its Levins-Wimsatt scheme of classification, is to supply a good part-whole dimensioned theory of realization that meets the Definition and Explanation conditions, not to establish that it is the only kind of part-whole theory that will meet those conditions.

5. Problems, Issues, and Conclusions.

In spite of the popularity of theories of realization based upon forms of scientific explanation, legitimate questions could be raised about their use as a theory of realization. I will discuss four that are relevant to [PWacme]. The first issue concerns explanations that appeal to wide facts versus narrow theories framed in terms of an individual's causal powers. Thus Robert Wilson (2001) would take issue with [PWacme]'s focus on the individual and its parts, endorsing instead a theory of wide realization that appeals to assorted semantic, social, and historical items outside the individual. And Polger (2007) would take issue with [PWacme]'s focus on causal properties, endorsing instead a broad notion of functional realization that subsumes paradigm cases such as the realization of abstract automata or machine tables that are not individuated by causal powers.

Yet, in response, perhaps one could extend [PWacme] in the desired directions, creating a wide part-whole theory that includes both external objects as parts of larger wholes along with any additional principles needed to explain a property of such extended wholes in terms of their parts. For example, in the case of historical evolution, one might treat a species as an extended spatio-temporal individual, and then explain the evolution of a species in terms of the selection

of traits among these member parts (Hull 1989; Winther 2011). To illustrate with the Giant Panda, one could view early member-parts with their small radial sesamoid bones as an initial temporal stage of the extended individual species, later member-parts with their larger bones as intermediate stages where selection occurred, and the present member-parts as a final stage where the members enjoy the larger bones that function as thumbs. Similarly, in the case of semantic externalism, one might postulate an extended mind that encompasses represented objects, and then explain the mind's beliefs in terms of relations between the parts that are represented and the parts that represent them. Or, what I think is the safer course, one could leave [PWacme] unchanged and simply to take it to provide a limited picture of the world that is compatible with wide theories. For example, in the case of wide semantic content, questions about the meaning of symbols within a cognitive system might be answered by a different kind of theory even when questions about the syntax of the symbols are answered by an individualistic theory about the parts, their causal properties, and their relations (see Endicott 2012 for an illustration).

The second issue concerns a possible conflict between realism and explanation. Some maintain, I think rightly, that scientific explanations are relative to the specific interests of the scientists who employ them (Wimsatt 1974; Machamer, Darden, and Craver 2000), or that they involve not only metaphysical facts in the world but also facts about understanding and communication (van Fraassen 1980; de Recht 2009). Someone might then worry that a theory like [PWacme] has the unwanted consequence that realization is mind dependent, as if the realization of a dinosaur's circulatory system by its parts actually depended upon the existence of explanatory practices by understanding minds that will exist in the future. Yet, in response, perhaps one could resist the irrealism by resorting to a purely metaphysical sense of explanation according to which facts explain things regardless of any cognitive or communicative features (e.g., Strevens 2000, p. 6, gives precedence to the metaphysical notion). But suppose good scientific explanations involve both. How does one avoid any unwanted mind dependence? Note that even if an explanation is relative to one's interests, it does not follow that the items *designated* by an explanation are interest relative or subjective. What is selected for attention may be objective facts in the world (see Lipton 1991, pp.123-25). Moreover, one may avoid any unwanted mind-dependence with the help of a counterfactual analysis. For [PWacme], one could stipulate that properties G_1-G_n "provide an explanation" for F means only that G_1-G_n *would*

allow one to better understand their relation to *F if* they were included in the pertinent part-whole explanations.

The third issue concerns a possible conflict between explanation and lawful determination. On the one hand, determination implies sufficient conditions. If *x* determines *y*, then *x* is a sufficient condition for *y*. On the other hand, it is a consequence of several plausible views about explanation that, among the multitude of factors that are jointly sufficient to produce some outcome, an explanation is typically selective inasmuch as it presents only a smaller group of factors that are especially relevant for the outcome in question. Consider Bas van Fraassen's (1980) example that spraying the plant with defoliant explains why it died even though the former is not a sufficient condition for the latter, given other factors and other contrasts that one might have in mind when asking why the plant died. Or consider Carl Craver's (2007) notion of constitutive relevance which does not require that the parts and properties cited in a mechanistic explanation enable one to derive the targeted phenomenon. As a consequence, on these and many other views, the items cited in an *explanans* typically do not supply a sufficient condition for the items targeted in the *explanandum*. One might then worry that the selectivity of explanation is inconsistent with the part-whole determination assumed by [PWacme].

Yet, in response, [PWacme] is wholly consistent. It may be true that the explanatorily relevant parts y_1-y_n and their part properties G_1-G_n cited in condition (iv^{acme}) do not supply a sufficient condition for *x* having the target property *F*, either individually or collectively, and yet it may also be true that what supplies a sufficient condition is those same lesser parts y_1-y_n having G_1-G_n, given assorted background conditions *B*, pace condition (iii). For example, whereas typical explanations for neurotransmission highlight facts about how positively charged ion atoms enter into the cell body and cause it to depolarize, these explanations assume a host of things that are required for a sufficient condition – that the myelan sheath which surrounds the axons has not been damaged or deteriorated, that the atoms are built from proper physical parts like quarks and leptons rather than immaterial monads that may defeat the function of a neuron at will, and so on. For convenience, let *B* represent an "ideal scientific text" that includes all such assumptions about the place of the pertinent parts and properties within the world (cf. Railton 1981). If *B* is so understood, then determination is guaranteed *via* a realization law of the form I have already employed in [PWacme]: it is necessary that if parts y_1-y_n have properties G_1-G_n, and *B* holds, then the whole *x* has *F*.

The fourth and final issue concerns part-whole determination and the potential for a promiscuous amount of multiple realization. Thus, Laurence Shapiro (2004, pp.44-57) argued that Gillett's original theory [D] trivializes the notion of multiple realization because there are a multitude of factors combine to determine the instantiation of a property. For example, in the case of neurotransmission, such facts include a solitary quark within the neural cell, and not just parts that are especially salient in the explanation for neurotransmission, such as having enough ion atoms enter through the cell's ion channels to cause depolarization. Thus, Shapiro argued, a change with respect to that solitary quark will count as an alternate realization on Gillett's view, rather than a change in something more functionally relevant to neurotransmission like the mechanism of ion channels. One might then worry that [PWacme] suffers from the same problem, being a development of Gillett's dimensioned view that accepts part-whole determination. Yet, in response, this is a point at which the main difference between Gillett's theories and my preferred theory pays dividends, for by [PWacme] only the parts y_1-y_n and their properties G_1-G_n that serve in one of the pertinent part-whole scientific explanations will count as a realization. For example, a mechanistic explanation for neurotransmission typically bottoms out well before the level of fundamental physics. So a solitary difference in the presence or absence of one quark in the neural cell body is typically irrelevant to the explanation. Indeed, Shapiro suggests that one may solve the problem by viewing realization in terms of the select group of parts that serve a Cummins-style functional analysis of the target system property. I suggest the same thing with respect to the selective group of parts and properties highlighted for attention in the explanations described by [PWacme].

No doubt there are more issues to consider. But, when measured against potential problems based upon familiar philosophical questions and debates, I believe that [PWacme] stands as a plausible theory of realization. So, in summary, I have argued that Gillett's dimensioned theories [D] and [Dm] are inadequate because they rest upon undefined terms like 'in virtue of" and "implement" that are not explanatory in the way expected from theories of realization. But I agree with Gillett's emphasis upon part-whole dimensions as well as the aim to capture a wide range of scientific explanations. I have therefore proposed a special part-whole mechanistic theory [PWme] as well as a preferred general part-whole theory [PWacme] that replace the stated undefined terms with an explicit reference to the appropriate range of explanations in the sciences.

Acknowledgments

I thank an anonymous reviewer for suggesting that I address the issue of potentially excessive multiple realization in the final section. I also thank Carl Gillett and Thomas Polger for many discussions of realization.

References

Aizawa, K., and Gillett, C. (2009). The (multiple) realization of psychological and other properties in the sciences, *Mind & Language* 24: 181-208.

Bechtel, W., and Richardson, R. (1993). *Discovering complexity*. Cambridge MA: MIT Press.

Block, N. (1980). What is functionalism?, in N. Block, ed., *Readings in Philosophy of Psychology* 1 (pp.171-84). Cambridge MA: Harvard University Press.

Cartwright, N. (1999). *The dappled world*. Cambridge UK: Cambridge University Press.

Chalmers, D. 1996. Does a rock implement every finite state automaton?, *Synthese* 108: 309-333.

Craver, C. (2001). Role functions, mechanisms, and hierarchy, *Philosophy of Science* 68 (1), 53-74.

_____. (2007). *Explaining the brain: Mechanisms and the mosaic unity of neuroscience*. New York, NY: Oxford University Press.

Cummins, R. (1975). Functional analysis, *Journal of Philosophy* 72: 741-65.

_____. (1983). *The nature of psychological explanation*, Cambridge MA: MIT Press.

_____. (1996). *Representation, targets, and attitudes*. Cambridge MA: MIT Press.

De Recht, H. (2009). The epistemic value of understanding, *Philosophy of Science* 76: 585-97.

Dolye, D., Cabral, J., Pfuetzner, R., Kuo, A., Gulbis, J., Cohen, S., Chait, B., McKinnon, R. (1998). The structure of the potassium channel: Molecular basis of K+ conduction and selectivity, *Science* 280: 69-77.

Durkheim, E. (1893/1997). *The division of labor in society*. Translated by W.D. Halls. New York, NY: Free Press.

Endicott, R. (2010). Realization, reductios, and category inclusion, *Journal of Philosophy* 107: 213-219.

_____. (2011). Flat versus dimensioned: The what and how of functional realization, *Journal of Philosophical Research* 36: 191-208.

_____. (2012). Resolving arguments by different conceptual traditions of realization, *Philosophical Studies* 159: 41-59.

_____. Functionalism and superduperfunctionalism: Lessons from supervenience, *Synthese* (forthcoming) [published online, 6 August, 2015, DOI 10.1007/s11229-015-0839-5].

Gillett, C. (2002). The dimensions of realization: A critique of the standard view, *Analysis* 62: 316-23.

_____. (2003). The metaphysics of realization, multiple realizability, and the special sciences, *Journal of Philosophy* 100: 591-603.

_____. (2007). Understanding the new reductionism: The metaphysics of science and compositional reduction, *Journal of Philosophy* 104: 193-216.

_____. (2013). Constitution, and multiple constitution, in the sciences: Using the neuron to construct a starting framework, *Minds & Machines* 23: 309-37.

Haug, M. (2010). Realization, determination, and mechanisms, *Philosophical Studies* 150: 313-30.

Haugeland, J. (1978). The nature and plausibility of cognitivism, *Behavioral and Brain Sciences* 1: 215-26.

Heil, J. (1992). *The nature of true minds*. Cambridge UK: Cambridge University Press.

Horgan, T. (1984). Functionalism, qualia, and the inverted spectrum, *Philosophy and Phenomenological Research* 44: 453-69.

_____. (1993). From supervenience to superdupervenience: Meeting the demands of a material world, *Mind* 102: 555-86.

Hull, D. (1989). *The metaphysics of evolution*. Albany: State University of New York Press.

Jensen, M., Jogini, V., Borhani, D., Leffler, A., Dror, R., and Shaw, D. (2012). Mechanism of voltage gating in potassium channels, *Science* 336: 229-33.

Kim, J. (1990). Supervenience as a philosophical concept, *Metaphilosophy* 21: 1-27.

_____. (1993a). Postcripts on supervenience, in *Supervenience and mind: selected philosophical essays* (pp.161-71). Cambridge UK: Cambridge University Press.

_____. (1993b). Nonreductivist troubles w mental causation, in *Supervenience and mind* (pp.336-57).

_____. (1997). The mind-body problem: Taking stock after forty years, *Philosophical Perspectives* 11: 185-207.

_____. (1998). *Mind in a physical world*. Cambridge MA: MIT Press.

_____. (2010). Two concepts of realization, mental causation, and physicalism, in *Essays in the metaphysics of mind* (pp.263-81). Oxford: Oxford University Press.

Lepore, E., and Loewer, B. (1989). More on making mind matter, *Philosophical Topics* 17: 175-91.

Levins, R. (1970). Complexity, in C.H. Waddington, ed., *Towards a theoretical biology*, vol. 3 (pp.67–86). Edinburgh: University of Edinburgh Press.

Lipton, P. (1991). *Inference to the best explanation*. New York, NY: Routledge Press.

Machamer, P., Darden, L., and Craver, C. (2000). Thinking about mechanisms, *Philosophy of Science* 67: 1-25.

Maudlin, T. (1998). Part and whole in quantum mechanics, in E. Casttellani, ed., *Interpreting Bodies* (pp.46-60). NJ: Princeton University Press.

McDermott, D. (1976). Artificial intelligence meets natural stupidity, rpt. in J. Haugeland, ed., *Mind Design* (pp.143-60). Cambridge MA: MIT Press, 1981.

Morris, K. (2010). "Guidelines for Theorizing about Realization," *The Southern Journal of Philosophy* 48: 393-416.

Piccinini, G. (2010). The mind as neural software? Understanding functionalism, computationalism, and computational functionalism, *Philosophy and Phenomenological Research* 59: 269-311.

Poland, J. (1994). *Physicalism*. Oxford: Oxford University Press.

Polger, T. (2007). Realization and the metaphysics of mind, *Australasian Journal of Philosophy* 85: 233-59.

_____. (2010). Mechanisms and explanatory realization relations, *Synthese* 177: 193-212.

Putnam, H. (1960). Minds and machines, rpt. in *Mind, Language and Reality: Philosophical Papers*, vol.2 (pp. 362-85). London: Cambridge University Press, 1975.

_____. (1967). The nature of mental states, rpt. in *Mind, language and reality* (pp.429-40).

Pylyshyn, Z. 1980: Computation and cognition: Issues in the foundations of cognitive science, rpt. in J. Garfield, ed., *Foundations of Cognitive Science* (pp.18-74). New York: Paragon House, 1990.

Railton, P. (1981). Probability, explanation, and information, *Synthese* 48: 233–56.

Rapaport, W. (1999). Implementation is semantic interpretation, *The Monist* 82: 109-130.

Schiffer, S. (1987). *Remnants of meaning*. Cambridge MA: MIT Press.

Searle, J. 1980. Minds, brains, and programs, *Behavioral and Brain Sciences* 3: 417-57.

_____. 1990

Shapiro, L. (2004). *The mind incarnate*. Cambridge MA: MIT Press.

Shoemaker, S. (1980). Causality and properties, in P. van Inwagen, ed., *Time and cause* (pp. 109-35). Dordrecht: Reidel.

_____. (2001). Realization and mental causation, in C. Gillett & B. Loewer, eds., *Physicalism and its discontents* (pp.23-33). Cambridge UK: Cambridge University Press.

Strevens, M. *Depth: An account of scientific explanation*. Cambridge MA: Harvard University Press.

Tye, M. (1995). *Ten problems of consciousness*. Cambridge MA: MIT Press.

Van Fraassen, B. (1980). *The scientific image*. Oxford: Clarendon Press.

Von Neumann, J. (1956). Probabilistic logics and the synthesis of reliable organisms from unreliable components, in C. Shannon and J. McCarthy, eds., *Automata Studies*: 43-98.

Walter, S. (2010). Taking realization seriously: No cure for epiphobia, *Philosophical Studies* 151: 207-26.

Wilson, R. (2001). Two views of realization, *Philosophical Studies* 104: 1-31.

Wilson, J. (1999). How superduper does a physicalist supervenience need to be? *Philosophical Quarterly* 49: 33-52.

_____. (2014). No work for a theory of grounding, *Inquiry* 57: 535-59.

Winther, G. (2011). Part-whole science, *Synthese* 178: 397-427.

Wimsatt, W. (1974). Complexity and organization, in K. Schaffner & R. S. Cohen, eds., *Boston Studies in the Philosophy of Science* 20: 67–86. Dordrecht: Reidel.

_____. (1986). Forms of aggregativity, in A. Donagan, N. Perovich, and M. Wedin, eds., *Human nature and natural knowledge*: Festschrift for Marjorie Grene (pp. 259-93). Dordrecht: Reidel.

_____. 2006. Aggregate, composed, and evolved systems: Reductionistic heuristics as means to more holistic theories, *Biology & Philosophy* 21: 667–702.