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Expanding the vector model for dispositionalist approaches to causation

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1 Introduction

Figures 1 and 2 should look familiar to philosophers studying causation.

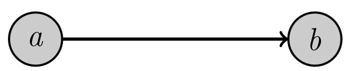

Fig. 1: A neuron diagram of a causing b

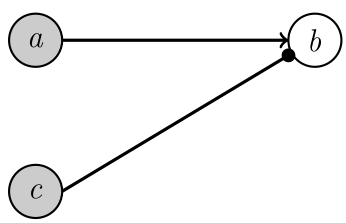

Fig. 2: A neuron diagram of a failing to make b occur due to the occurrence of c, which is an inhibitor of b.

Such neuron diagrams occupy a central place in discussions of causation, with the circles representing causal relata, and the arrows representing causal connections.

Taking the relata to be events, if a circle is shaded, then the event is represented as occurring, while a non-shaded circle indicates its non-occurrence. These shading options can aid in representing an inhibiting connection between events, for example. In Fig. 2, c is an inhibitor of b, with its inhibiting connection being represented by a line terminating in a dot at b. So, despite the occurrence of a and its causal connection to b, the occurrence of inhibitor c prevents b from occurring, rendering the representation of that event unshaded.

Notwithstanding the dominant convention of employing neuron diagrams to model causation, Stephen Mumford and Rani Lill Anjum (2011a, pp. 21-22; 2011b) argue that the neuron model has multiple shortcomings, especially when employed within a dispositionalist approach. For example, neuron diagrams suggest that causal relata are discrete, self-contained entities, such that their identities or natures are entirely independent of the causal relations in which they stand. But this conflicts with the dispositionalist view that dispositions are tied to their potential manifestations *essentially*. Mumford and Anjum (henceforth: M&A) also worry about the neuron model's tendency to focus on only one cause—*a* cause rather than the complex, total cause consisting of *many* causes. Dispositionalist accounts of causation take seriously the prospect of multiple powers at work, so that characterizations of causal situations typically require appreciating more than simply a single disposition.[1] These sorts of concerns are pressing because, as Christopher Hitchcock warns us, "the way in which we choose to *represent* some phenomenon can shape the way in which we think about that phenomenon" (2007, p. 69). Thus, M&A conclude:

[1]M&A treat the terms "power" and "disposition" as equivalent, which I will do as well.

> What we need, therefore, is a better way of representing causal situations: one that is more sympathetic to an ontology of powers and what they would bring to the theory of causation. We need a causal model for a truly interconnected, rather than 'loose and separate' world. (2011b, p. 58)

Even if one can successfully defend neuron diagrams as friendly to dispositionalism, or augment them to be so (perhaps using a Bayesian network approach), M&A's concerns still emphasize a valid need. It is important that a dispositionalist approach avoid models that hinder appreciation of its account of causation or, even worse, encourage ontological biases against dispositions themselves. And M&A (2011a; 2011b) do devote extensive efforts towards meeting this need, with the development of their vector model. The primary aim of this paper is to capitalize on those efforts by expanding their model.[2] While M&A's vector model might be conducive to representing their particular brand of dispositionalism, it will be argued that it is not similarly able to serve the representational needs of other powers-based accounts of causation, hindering its value from a broader, methodological perspective. After highlighting those limitations, I will offer ways of improving upon the vector model so as to expand its representational power. We will therefore not engage in a general defense of the vector model but, rather, concentrate on this constructive project of improving its flexibility.

[2]Again, this will not require adopting their pessimistic view of neuron diagrams but, rather, require appreciating M&A's underlying goal of securing a dispositionalist friendly model, which we will pursue within the vector approach.

2 M&A's vector model

In order to present some basic elements of M&A's vector model, consider Fig. 3.

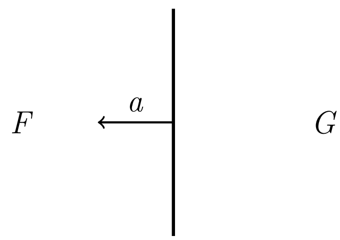

Fig. 3: A disposition towards F

Here, we have a single vector plotted on a one-dimensional quality space. The quality space spans between two extremes, F and G (e.g., hot and cold, fragile and sturdy, acidic and alkaline), with a centered vertical line representing the starting point. The vector, a, represents a single disposition exercising its power in a certain direction (indicated by a pointing arrowhead) with a certain intensity (indicated by the vector's length).

As one would expect, given their concerns with the neuron model, M&A are quick to point out that standard cases of causation will typically involve multiple powers. According to M&A, powers often combine, with either additive or subtractive effects on one another, to yield an overall disposing of the relevant object. This overall disposing is represented by a resultant vector, which is decided by vector addition. Consider, for example, Fig. 4.

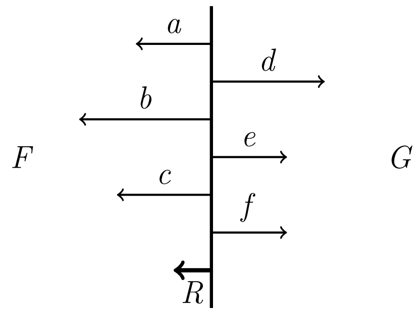

Fig. 4: Multiple powers and their resultant

Suppose we are concerned with the ambient temperature of a room, and F represents being hot and G represents being cold. There can easily be a variety of powers aiming at raising the temperature of the room (e.g., those belonging to a stove with its burners on, sunlight coming through a window, a sweaty chef hard at work), as well as a variety of powers directed towards lowering its temperature (e.g., those belonging to an open refrigerator, a running air-conditioner, a draft from a cold basement). With each of those powers being represented by a vector, assume the following values for their intensities: $a = 4$, $b = 7$, $c = 5$, $d = 6$, $e = 4$, $f = 4$. With 16 units of intensity disposing towards F and only 14 units disposing towards G, the resultant vector, R, has 2 units of intensity in the direction of F. Thus, the active powers in the room that are relevant to its ambient temperature can be combined, through vector addition, to yield an overall disposing of the room to be warmer.

The ability to perform vector addition is an attractive feature of the vector model, as it speaks to the need for representing multiple powers at work. This is not to say that such an employment of vector addition is without challenges, or that modeling powers as vectors is uncontroversial.[3] However, the central task of this paper (as already stated) is not to engage in a general defense of the vector model but, rather, to help make the model as versatile as it can be for accommodating dispositionalist approaches to causation. So, in the next section, I will distinguish between three ways of relating the workings of multiple powers and, in the section after that, make clear the limitations of vector addition with respect to two of them. This will help motivate the introduction of additional representational tools in later sections, where we will work to make the vector model more friendly to a variety of dispositionalist ontologies.

[3]As M&A (2011a, ch. 4) acknowledge, vector addition cannot handle genuine cases of non-linear composition. Vector addition, as an additive mode of composition, requires that the output of a system be proportional to the input: $f(x + y) = f(x) + f(y)$. But there are arguably real world systems that violate this principle, such as the weather with the butterfly effect. For M&A's handling of this issue, see their 2011a, ch. 4.

Moreover, vector addition in general seems to presume a degree of objective precision regarding the *magnitude* and *direction* of a power, which one might question as well (e.g., Elina Pechlivanidi and Stathis Psillos, unpublished). Fragility, for instance, is determined by the degree of pressure it takes an object to break relative to a certain context (e.g., the typical handling conditions of a vase) or the degree of pressure it takes an object to break relative to another object (e.g., a crystal vase vs. a copper vase). Indeed, such points might be pressed to challenge the *very idea* of modeling powers as vectors.

Another basic concern with the vector approach is that it cannot represent inactive or dormant powers (e.g., Jennifer McKitrick and Anna Marmodoro in McKitrick et al. 2013). As M&A explicitly state, "vectors represent only the powers that are exercising or operating" (2011a, p. 38). But a key feature of dispositionalism, which takes powers to be more than *mere* potentialities, is that powers can exist without manifesting or even being active at all—they can exist "ready to go." Therefore, interacting powers should be able to yield results that involve inactive powers, which the vector model would be unable to represent. For M&A's response to this apparent weakness of the vector model, see McKitrick et al. 2013.

3 Three kinds of power relations

One standard way of characterizing dispositions is in terms of how they would manifest, given certain *stimulus* conditions. Fragility, for instance, is often characterized in terms of the power to break when struck, where the striking is a stimulus condition and the breaking a response. Since stimulus conditions typically involve powers at work, this suggests a stimulus-response relation for characterizing the dependence of one power's activity on another power's activity. When a fragile vase, for example, is struck, there is a striking agent exercising its own power(s). Take the agent to be a boy with a bat. In order to be a stimulus of the vase's fragility, the boy must exercise his power to strike the vase. In doing so, he would activate (or at least work to activate) the disposition of the vase to break. Thus, the manifestation of a stimulating power involves the activation of another power, with that responding power in turn pursuing its own manifestation.[4] Although such stimulation relations have significant currency in discussions of dispositions, dispositionalists do propose other ways of relating the activities of powers.

A second way of construing the efforts of multiple powers focuses on cooperation between dispositions. C. B. Martin (2008) argues that all manifestations of powers are *mutual* manifestations, such that a power manifests itself only when it meets a disposition *partner*. You cannot have, for instance, an object manifesting its gravitational mass (disposition to attract) alone; any manifestation of gravitational mass will require two objects *mutually* manifesting their *reciprocal* dispositions to attract

[4]A responding power could itself be a stimulating power as well. This would be the case for fragility, were the breaking of the vase to involve the activation of a further power (e.g., a disposition of the delicate display table to scratch).

one another. Martin's position is shared by his longtime collaborator, John Heil (2012), who rejects the "received view" of causation, according to which causation is an asymmetrical relation between distinct events. Heil does not see causation as involving one event, the cause, asymmetrically bringing about another event, the effect. Rather, he sees causation as a *mutual* manifestation of *reciprocal* powers, so that causation is a *symmetrical* and *cooperative* affair. Two cards leaning against each other upon a table, for instance, remain upright because they are (with assistance from the table) *mutually* supporting: "The cards' remaining upright is a continuous mutual manifestation of reciprocal powers possessed by the cards and the table" (Heil 2012, p. 119).

To better appreciate the difference between a mutual manifestation and a stimulation, it helps to pay attention to what the relevant dispositions are essentially for—specifically, whether or not they aim at one and the same manifestation. Consider again the example of gravitational mass, as a case motivating the mutual manifestation approach. When two objects with the power to attract are paired, it is not as though they trigger or stimulate each other to go about securing distinct, individual manifestations. Rather, the reciprocal powers work together to secure a manifestation (e.g., the objects moving closer to one another) that they are both for, or at which they both aim. This is precisely why it is a *mutual* manifestation and requires powers relating to one another in a deeply cooperative fashion not found in the stimulus-response relation.

A third way in which multiple powers might be related is through the combining of private contributions. On this account, powers do aim at their own, distinct manifestations, but those individual efforts (or corresponding manifestations) can combine so as to yield certain results. George Molnar, for instance, holds such a view:

> A manifestation is typically a *contribution* to an effect, an effect is typically a *combination* of contributory manifestations. In other words, events are usually related as effects to a collection of interacting powers. Each power has one manifestation, each manifestation is the product of the exercise of one power. Of course, this contributory manifestation does not determine the effect on its own. The effect depends on the exact 'mix' of contributions by *all* the contributing powers. (2003, p. 195)

Although such contribution combinations involve powers pursuing distinct manifestations, this sort of relation remains importantly different from the stimulus-response relation. Stimulation primarily concerns the activity of one power making another power active, while contribution combination does not, as the activity of the powers being related is already given. Indeed, notice that contribution combination is compatible with the related powers acting spontaneously, or unstimulated. Contribution combination requires that powers make contributory efforts or manifestations, leaving open what, if anything, prompted those powers to make those contributions.

We have, then, three ways in which the activities of multiple powers might be related (which, for simplicity, are formulated with a focus on only two powers, but can be appropriately expanded so as to involve several powers):

> *Stimulation*: A stimulating power makes (or at least works to make) it the case that another power works towards its own, distinct manifestation.

> *Mutual manifestation*: Two powers work as reciprocal partners, such that they together bring about (or at least work to bring about) one and the same manifestation. Neither disposition involved is aiming at its own, distinct manifestation.
>
> *Contribution combination*: Two powers work towards their own, distinct manifestations but interact—through the combining of those individual efforts or corresponding manifestations—so as to bring about (or at least work to bring about) certain results.

To be clear, these formulations specify whether or not two powers are aiming at the same manifestation *token*. For *mutual manifestation*, it is not enough to have the powers working towards the same manifestation *type*. Two powers pursuing distinct tokens of the same manifestation type are not engaging in the deeply co-operative efforts specific to mutual manifestation partners. Regarding *stimulation* and *contribution combination*, neither requires that the related powers be for different manifestation *types*. A stimulating power and a responding power can aim at distinct tokens of the same manifestation type (e.g., one domino's power to strike another domino stimulating that second domino's power to strike another domino), and a contribution combination can involve contributory manifestations of the same type (e.g., a sound of 100 decibels resulting from contributory manifestations made by two singers each hitting 50 decibels).

With these three kinds of power relations sufficiently distinguished, let us now turn to examining the ability of vector addition to accommodate them.

4 Limitations of vector addition

M&A consider the following worry:

> The vector model suggests that if there were just one power at work [as depicted in Fig. 3], then it would have to move towards [F] on its own, unaided by any mutual manifestation partner... Some might find this unacceptable on the grounds that it amounts to a power that might be able to manifest itself unstimulated or spontaneously. If it is implausible that powers can behave this way, then it might be thought of as a restriction on the vector model or, worse, that the vector model indicates the wrong results in such a situation. If we just had the flammability of a match, for instance, with no further powers at work, then it could be objected that it would never light on its own. If there were something fragile, with no other powers working with it, then it wouldn't just break on its own without being struck. (2011a, p. 35)

In quickly moving from a power manifesting "unaided by any mutual manifestation partner" to manifesting itself "unstimulated," M&A are not being as sensitive as we have been to the corresponding distinction highlighted in the previous section. But let us suppose they are focused on stimulation, as we have specified it. Their presentation of the concern of a lonely power suggests that while the power represented by vector a in Fig. 3 is engaging in an unstimulated manifestation, it no longer would be in the case represented by Fig. 5.

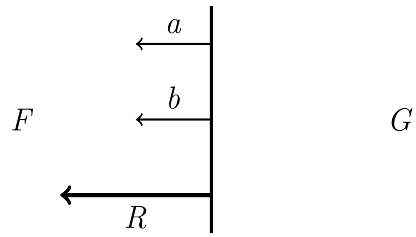

Fig. 5: A simple case of vector addition

However, the additional power represented by vector b does not appear to be stimulating or in any way responsible for the fact that the power represented by vector a is active at that time. Vector b is not directed towards vector a at all. And without any such aim at vector a, it is entirely unclear how adding vector b to vector a is supposed to capture the stimulation of the power represented by vector a.[5] So, while M&A's discussion of spontaneous or unstimulated powers suggests that vector addition can represent the stimulation of a power, it turns out to have no such representational ability.

The situation is no better for representing mutual manifestations. After considering Martin's position and the case of gravity, M&A appear to appreciate the motivations for mutual manifestations occupying a central place in a powers approach to causation:

> Effects are almost always produced by many powers acting together. The same power can produce different overall effects depending on which other

[5]One might be tempted here to put vector addition aside and, instead, appeal to the centered vertical line in order to connect the two powers. However, that line represents merely our starting point in the quality space. Moreover, the stimulation relation is asymmetrical, yet the vertical line suggests no such directionality between the powers represented by vectors a and b.

> powers combine with it. Powers can thus have different partners for the production of different mutual manifestations. (2011a, p. 35)

And according to M&A, the collective efforts of various powers is captured nicely by vector addition, with a mutual manifestation represented as a resultant (or that at which the resultant aims).

Although initially attractive, closer inspection reveals that vector addition is, in fact, not up to the task of representing mutual manifestations. Consider again the simple case of vector addition in Fig. 5. Notice that each component force is still represented as if it could yield a manifestation on its own. Each component force is represented by its own, distinct vector, suggesting the same degree of autonomy as would be suggested by diagramming each of those vectors alone. Granted, vectors a and b represent the two powers as aiming at the same *type* of manifestation. But, again, that is not sufficient for the deeply cooperative efforts defining of a mutual manifestation.[6]

We are now down to contribution combination. Here, vector addition is far more promising, as it can easily be seen as representing the combining of the private contributions of multiple powers. Moreover, it appears that this is the very sort of dispositionalist ontology that M&A (2011a, p. 224) favor, as they follow Molnar's individuation of powers using distinct types of manifestations. It should be no surprise,

[6] Christopher Austin (2015) is also sensitive to the difficulty M&A's vector model faces in trying to represent mutual manifestations. However, Austin does not take this to be a problem, since he does not think that mutual manifestations need to be included in a dispositionalist approach to causation. The primary aim of this paper, though, is not to settle such debates among alternative dispositionalist ontologies but, rather, to help provide a general model for representing those various approaches to causation. In which case, the inability of vector addition to represent mutual manifestations remains a concern for us, as we are interested in the value of the vector model from a broader, methodological perspective.

then, that vector addition is nicely equipped to represent the combining of individual contributions made by powers aiming at their own, distinct manifestations.

There remains the exegetical question of whether M&A ultimately take vector addition to be capable of representing stimulations and mutual manifestations (in addition to their preferred contribution combinations). Granted, their employment of stimulation and mutual manifestation terminology, as well as their sympathies with Martin's approach, suggest as much. But it might nonetheless be the case that M&A have a much more limited purpose in mind with their use of vector addition. That is, perhaps they do not actually take vector addition to be able to serve further as a representational tool for either stimulations or mutual manifestations, restricting its intended service to contribution combinations, for which it does look well suited. If so, the limitations just raised for vector addition should not be taken to be causes for concern for M&A.

For those dispositionalists, however, who are interested in stimulations and mutual manifestations, vector addition's limitations should be troubling. This becomes all the more clear when one considers the option of settling for the representational devices within M&A's vector model and trying to interpret them (via general commentary) along the lines of a stimulation or mutual manifestation ontology. If too much of one's dispositionalist approach to causation is limited to an interpretation of the vector model, then relevant details are vulnerable to being mishandled or neglected. Regarding stimulation, for example, one might propose simply stipulating that every power represented by a vector is stimulated by some other power. But approaching causation with a stimulation ontology does not necessarily require taking *all* active powers to be stimulated; one might allow for rare instances of spontaneously active powers. Even setting such cases aside, there is the issue, for any given diagram involving multiple vectors, of whether the represented powers are stimulated by the same power or different powers. Thus, a broad assumption of stimulation would leave something to be desired in terms of the vector model's sensitivity to potentially important details.

More broadly, relying so heavily on the interpretation of (or commentary on) the vector model robs us of the ability to contrast different theories using the representational devices of the model. This is problematic from a wider, methodological perspective. When considering the general dispositionalist project, it is preferable to have a model flexible enough to represent a variety of positions, so that dispositionalists' ontological options can be properly considered as they attempt to iron out their best accounts of causation. Suppose you were attracted to dispositionalism, but had not yet settled on a particular powers-based account of causation. In shopping for the right one, you would want to be able to compare the alternatives as fully and fairly as possible. And, as Hitchcock warns us, "the way in which we choose to *represent* some phenomenon can shape the way in which we think about that phenomenon" (2007, p. 69). From such a methodological perspective, it is therefore desirable to have a more flexible model that can represent not only contribution combinations but also stimulations and mutual manifestations. Furthermore, in order to explore various ways in which the different kinds of power relations might be combined, it would help to have their corresponding representational tools be compatible with one another.

In this section, we have motivated the need to supplement the vector model with additional representational tools. While vector addition is well positioned to represent contribution combination, it is not similarly capable with respect to the other two power relations, stimulation and mutual manifestation. This is problematic not only for advocates of such relations but also from a more general, methodological perspective. And it would be preferable to adopt representational tools that are compatible with vector addition, as well as one another, so as to facilitate research into how the corresponding relations might be combined. Over the next two sections, I will attempt to so broaden the vector model, beginning with the representation of stimulation.

5 Expanding the vector model: stimulation

Despite the limitations just discussed, the vector model can be fruitfully augmented in various ways. In order to represent a stimulating power, we can make use of a box at the beginning of a vector, with that vector representing a responding power. Figure 6 illustrates this technique.

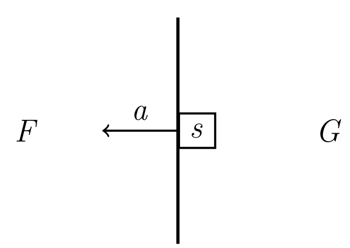

Fig. 6: A power, s, stimulating the manifestation of another power, a

The use of a box enables us to tie a stimulus to a corresponding response, without inappropriately implying that the two powers are for one and the same manifestation. The box occurs at the beginning of the vector, so as to make clear that the manifestation of the stimulating power involves the activation of another power, with the activated power in turn pursuing it own, distinct manifestation.

This way of representing stimulation does treat the relation as synchronic, since a single diagram is supposed to represent dispositional activity at a single time. But unlike the other two power relations (mutual manifestation and contribution combination), stimulation is typically treated as a diachronic relation.[7] This can be accommodated by adding time indexes to the box and vector representing our modeled stimulus and response (e.g., s_{t1}, a_{t2}), thereby making evident that the activity of the stimulating power occurs before that of the responding power. The box-to-vector tool thus enables stimulation, in both synchronic and diachronic forms, to make its appearance within the vector model.

The box-to-vector approach is clearly compatible with vector addition, where the vectors are added just as they would be without the attached boxes. This enables one to represent a stimulated contribution combination: a contribution combination involving contributing powers (represented by vectors) that are stimulated by other powers (represented by boxes). Still, more work is required in order to make the composition of a stimulating power available for vector addition. Since the box is

[7]Matthew Tugby (2010) highlights the heavy favoring of a diachronic approach. He also challenges it, arguing in favor of a synchronic account of stimulation. One might expect, then, that Tugby would be content with the suggestion on offer. It seems to me, however, that Tugby is not really after stimulation but, instead, promoting a mutual manifestation ontology (see especially pp. 333-334). So, Tugby would probably prefer employing my strategy for representing mutual manifestations, which will be proposed in the next section.

not a vector, one cannot apply vector addition in order to represent the component powers of a stimulus. Also, this lack of vectors for stimulating powers highlights a general limitation of the box-to-vector approach: the intensity with which a stimulating power operates is, at best, represented as *sufficient* for the activation of the corresponding power. Yet one might want greater precision regarding the intensities of stimulating powers.[8]

So, instead of letting a box *directly* represent a stimulating power, let it *indirectly* do so by referring to a quality space concerning the activity of the power that the stimulating power is aiming to promote. Consider Fig. 7.

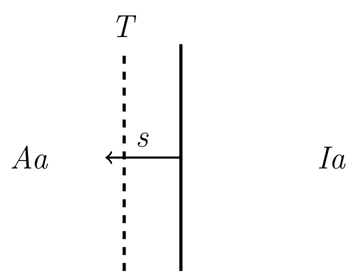

Fig. 7: A stimulating power represented by a vector

Here, we have a one-dimensional quality space, where Aa represents the power a being active, and Ia its being inactive. Employing M&A's (2011a, pp. 72-74) strategy for representing a threshold, the threshold for activating a is represented by a dashed

[8]It is tempting here to try to gauge the intensity of a stimulating power using the intensity of the stimulated power. Remember, however, that the two powers aim at different manifestations, which makes it difficult to see how such a connection is assured between their respective intensities. Notice as well that such an approach would be rendered problematic were the intensity of a power allowed to be greater than that which is necessary for it to stimulate another power (e.g., a bridge's disposition to collapse under 6 tons of weight being stimulated by a 7-ton vehicle).

line, T. Should the stimulating power involve component powers in need of representation, multiple vectors can be introduced and combined through vector addition. Hence, the modification on offer allows for greater sensitivity to the intensity of a stimulating power, as well as the ability to represent its composition using vector addition.

With this adjustment, the box-to-vector tool remains important when vector addition is applied to responding powers, for it permits those powers to still be represented *as stimulated*. Yet it does not overly burden such diagrams with details regarding the stimuli, as the box is a convenient way of referring to another diagram that provides further information. Note as well that one can continue to use the time-indexing method mentioned earlier, so as to accommodate both synchronic and diachronic approaches to stimulation.

6 Expanding the vector model: mutual manifestation

Turning to mutual manifestations, the core difficulty with M&A's model is that each power has its own, distinct vector. Even with vector addition, the private nature of vectors prevents those powers from being seen as engaging in the deeply cooperative efforts constitutive of a mutual manifestation. A natural way of overcoming this difficulty, then, is to let a single vector represent multiple powers. Doing so enables our modified vector model to represent those powers as reciprocal partners in generating the direction and intensity of a *shared* vector. One way to execute this modification would be to represent each partnered power with a term and bracket them together. Figure 8 provides a simple example, involving two disposition partners, a and b.

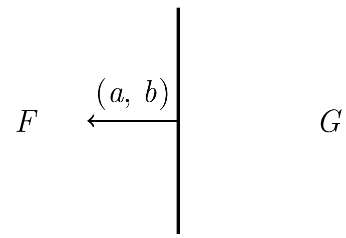

Fig. 8: A shared vector representing mutual manifestation partners working towards F

Notice that shared vectors are compatible with the box-to-vector approach. Should one be interested in representing the stimulation of a mutual manifestation, a box can be inserted at the beginning of a shared vector. And since a box can be supplemented with a vector graph of its own, there is also room for a shared vector to represent stimulating powers as engaging in a mutual manifestation. Heil's position, for instance, might be interpreted along such lines. As mentioned earlier, he favors the cooperative efforts of a mutual manifestation, which he calls a *causing*, over the asymmetrical understanding of causation in terms of cause and effect. However, Heil (2012, p. 120) still allows room for the notion of a *cause*, where a cause is the bringing together of disposition partners, thereby prompting those partners to mutually manifest (i.e., prompting a *causing*). Such a cause appears to be a stimulus, but one activating reciprocal partners. Moreover, for Heil, causes will themselves involve powers working together, mutually manifesting, in order to get other powers appropriately partnered. Thus, Heil's causes would appear to be modeled effectively using a box-to-vector approach, in which the representations of both the stimuli and the responses employ shared vectors.[9] In any event, the compatibility of shared vectors with the box-to-vector approach is worth appreciating, as we are looking to make the vector model as flexible as possible and thereby facilitate exploration of a variety of dispositionalist ontologies.

Shared vectors are compatible with vector addition as well. Figure 9 provides an example of how shared vectors might figure into vector addition.

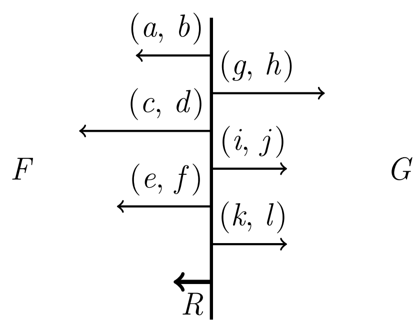

Fig. 9: A vector addition with shared vectors

In this case, we have vector addition modeling how forces—some (mutually) disposed toward F and others (mutually) disposed toward G—might interact. The interaction is a sort of contribution combination, but one in which each contribution is jointly made by disposition partners.

[9]The ability to employ time-indexing would also prove useful here, as Heil's causes appear to precede their resulting causings. In the example involving two cards remaining upright upon a table, for instance, the cause (carefully placing the cards upon the table) precedes the resulting causing (reciprocal powers of the cards and the table mutually supporting the cards' remaining upright).

Up to this point in our discussion of shared vectors, each represented power has been limited to a single shared vector. However, those with a "multi-track" view of dispositions would no doubt appreciate the ability to represent a power engaging in different kinds of mutual manifestations with different kinds of disposition partners. For example, consider a spherical boulder in the path of a wind, such that the direction of the wind is altered in a curved fashion. Suppose we also introduce to the boulder a certain angle of lighting and a flat surface, such that a curved shadow is cast. Here, one might take a multi-track approach to the sphericity of the boulder, and view that power as manifesting itself differently due to the presence of different kinds of disposition partners. Shared-vector modeling would accommodate such a view by allowing the boulder's sphericity to occupy two shared vectors, one in which it is partnered with the relevant powers of the wind, and another in which it is partnered with the relevant powers of the lighting and flat surface. And these two shared vectors would occupy different quality spaces, one concerning the direction of the wind and the other concerning the shape of the shadow.

A multi-track dispositionalist might also find it useful to have a single power represented in multiple shared vectors in the same quality space—indeed, even in multiple shared vectors going in *opposite* directions of a quality space, as illustrated by Fig. 10.

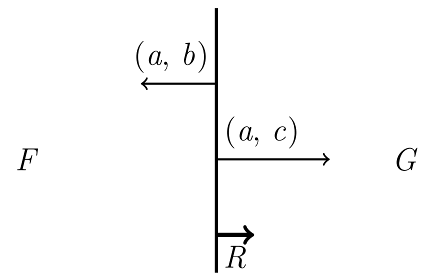

Fig. 10: A vector addition with two shared vectors featuring the same power

Take, for instance, a particular object, O, with a certain mass (power to attract), a. For our quality space, let F be the object moving to the left, and G its moving to the right. Now, if a were paired with a much greater mass, b, belonging to an object 10 feet to the left of O, the two powers would work towards the mutual manifestation of O moving to the left with a certain degree of intensity. Alternatively, if a were paired with a mass, c, which is even greater than b and belongs to an object 10 feet to the right of O, the two powers, a and c, would work towards the mutual manifestation of O moving to the right with a certain (greater) degree of intensity. Now suppose that we simultaneously introduce each of those more massive objects on those opposite sides of O. Figure 10 affords us the expressive resources to capture the two different partnerships involving a and, using vector addition, how the two partnerships interact to yield a resultant, R.

Of course, it is a substantive scientific and metaphysical issue whether Fig. 10 best represents O's causal interaction with the two, more massive objects. On the metaphysical end, for instance, one might argue that since a is working with b and c in the same quality space, a should be seen *not* as working towards one mutual manifestation with b and another (distinct) mutual manifestation with c but, instead, as working towards a *single mutual manifestation* with b and c, making them all disposition partners. With Fig. 11, shared-vector modeling can accommodate this alternative account, according to which a, b, and c are disposition partners, working together for the mutual manifestation of O moving to the right with a certain degree of intensity.

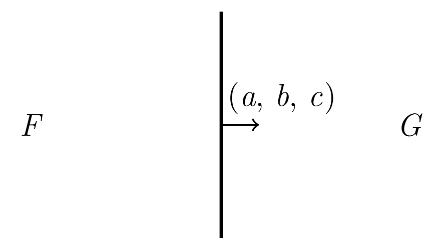

Fig. 11: A shared vector representing three disposition partners for a single mutual manifestation

The metaphysical debate over whether those three powers to attract are all such disposition partners, which largely concerns how to individuate dispositions and their corresponding mutual manifestations, is not one to take up here, however. Instead, the availability of the choice between Fig. 10 and Fig. 11 is to be taken to highlight the ability of the shared-vector approach to accommodate a variety of dispositionalist ontologies, thereby increasing the general, methodological value of the vector model.

A potential worry, though, is that shared vectors are too coarse grained, in that they are unable to represent the individuality of the dispositions involved in a mutual manifestation. A chief benefit of multiple vectors and, in turn, vector addition, is a more fine-grained modeling of how powers interact, rather than simply lumping them into a single vector from the outset. How can one tell whether the disposition partners represented in Fig. 8, for instance, are both dispositions toward F or, instead, one towards F and one (with a lesser degree of intensity) towards G?

In responding to this concern, recall that the entire point of a shared vector is to capture the cooperative efforts of a mutual manifestation, in which none of the disposition partners involved are aiming at its own, distinct manifestation. Regarding Fig. 8, then, it is actually a virtue of the shared-vector approach that each disposition partner involved is not represented as able to secure *on its own* a manifestation in either the F or G direction of the quality space. Mutual manifestations are not as piecemeal as the addition of multiple vectors suggests. So, while the fine-grained nature of vector addition gives you, in a sense, more detailed representations than do shared vectors, those extra details do nothing to help capture mutual manifestations but, rather, misrepresent them! Therefore, to the extent that one takes certain dispositions represented in a given quality space to be mutual manifestation partners, those dispositions should be represented in a single (more coarse-grained) shared vector.

Moreover, it is not as though shared vectors entirely prevent one from representing the individuality of dispositions involved in a mutual manifestation. Notice that one can model an interventionist manipulation, using a second vector graph in which an original disposition partner of interest is no longer present. The difference between the two graphs would provide a picture of the manipulated power's reciprocal role.[10] Taking a multi-track approach towards the disposition of interest,

[10]Feel free to assume that the original shared vector of interest involves more than two powers, so that the second graph will not involve a non-shared vector. Notice, though, that the suggestion on

a further resource becomes available, as the disposition is capable of many other kinds of mutual manifestations involving various disposition partners, which can be represented by other shared vectors. Those additional shared vectors would provide a sense of the disposition's distinctive mutual manifestation profile—its identity. So, there are strategies for representing the individuality of dispositions grouped in a shared vector, despite its coarse-grained nature.

7 Conclusion

In this paper, M&A's vector model has been expanded so as to accommodate a wider range of powers-based accounts of causation. This required moving beyond mere vector addition, which was tailored to represent contribution combinations. We introduced boxes (and corresponding vector graphs) at the beginning of vectors to represent stimulations and shared vectors to represent mutual manifestations. Furthermore, all three of these expressive resources were shown to be compatible with one another. The result is a significant increase in the representational flexibility of the vector model, making it a more versatile resource in the development of a variety of dispositionalist approaches to causation.

offer would then involve a multi-track approach towards those dispositions remaining in the second graph, since they will be represented by a shared vector involving a different set of reciprocal dispositions for a different kind of mutual manifestation.

Acknowledgements: I am grateful to Jacob Caton, Neil Williams, Jessica Wilson, audience members who heard conference versions of this paper, and four anonymous referees for their helpful feedback. I also owe a special thanks to Adam Podlaskowski, who read several drafts, provided a ton of useful comments, and engaged me in fruitful discussions regarding a variety of ideas in this paper.

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