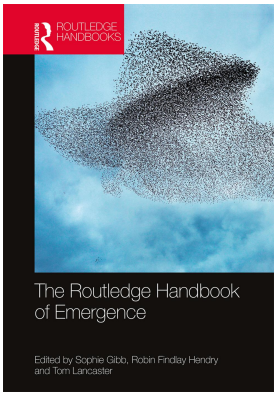


# The Routledge Handbook of Emergence

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## Emergence, Downward Causation and its Alternatives

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# 7

# EMERGENCE, DOWNWARD CAUSATION AND ITS ALTERNATIVES

## Critically surveying a foundational issue

*Carl Gillett*

Contemporary scientific emergentism, defended by physicists like Philip Anderson and Robert Laughlin, neuroscientists like Walter Freeman, and many others, takes as its starting point our present scientific evidence that includes "horizontal" causal explanations/models but also ubiquitous "vertical" compositional explanations/models.[1] Crucially, the latter explanations show how almost all higher-level scientific entities, whether individuals, or their activities and properties, are composed by lower level entities.

Scientific reductionists like Steven Weinberg (1994), have long argued that when we have such compositional explanations then this suffices to show that "Wholes are nothing but their parts" and hence that such lower-level parts are the only determinative entities. But inspired by concrete examples from superconductors to slime mold, scientific emergentists have challenged such reasoning by articulating a contrasting picture where we have "emergent" composed entities. The core of this position is depicted in Figure 7.1 by a prominent emergentist in complexity science.

As the figure highlights, scientific emergentists accept that emergent wholes are composed – hence the upward arrow of composition from the parts to the whole – but the scientific emergentist also claims the emergent whole to be "downwardly" determinative upon its parts. As a result, the scientific emergentist now routinely claims, "Parts behave differently in wholes," and argues that this supports her further contention, contra the reductionist, that emergent entities are determinative and that "Wholes are more than the sum of their parts". The diagram thus highlights the core commitment of scientific emergentism to what I will term the "foundational determinative relation" (FDR) by which emergent wholes downwardly determine their parts and around which many of the novel claims of scientific emergentism are founded.

A key task for scientific emergentism is providing a theoretical account of FDR that coheres with the position's other commitments. My focus in this chapter is to critically survey differing treatments of FDR, and my discussion is therefore solely about the species of "emergence" found in the situation framed by Figure 7.1 and endorsed by contemporary scientific emergentists. There are obviously many *other* species of emergence not committed to anything like FDR.

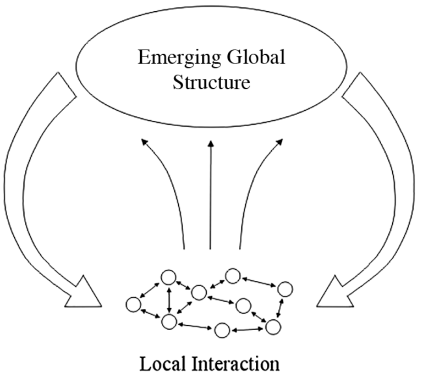


*Figure 7.1* Chris Langton's famous diagram of scientific emergence with compositional relations going upwards from the parts to the emergent whole and the foundational determinative relation coming down from the whole to the parts.

[From Lewin (1992), Figure 10, p. 189]

For example, those who take emergent entities to be uncomposed, or who take emergence to do purely epistemic work, endorse nothing like FDR. To make my narrow focus clear, I will use the term "scientific emergence" to refer to the kind endorsed by scientific emergentists.[2]

Philosophers and scientists have offered a number of suggestions about the character of FDR, including that it is:[3]

*A Boundary Condition* – Michael Polanyi (1968) famously suggested that the emergent whole is a boundary condition on its parts;

*Control* or *Constraint* – the theoretical biologist Pattee (1973), and others following him, suggests that emergent wholes constrain, or bear relations of control to, their parts;

*Reduction in Degrees of Freedom* – Pattee (1973) and others press the related suggestion that emergent wholes result in reductions in the degrees of freedom of their parts.

However, all of these accounts plausibly appear to frame characteristics of FDR, rather than providing an account of the deeper character of this relation. And there appear to be just two competing families of views about the ontological nature of FDR.

By far the most popular approach takes the familiar determinative relation posited in "horizontal" causal explanations and then claims it also holds "downwardly" from the emergent whole to its parts:

*Downward Causation* – FDR is the relation, or same kind of relation, that we find posited in causal models/explanations between the properties or activities of distinct individuals.

The key question for accounts of FDR as downward causation is whether causation has features that can fit with the characteristics we find in cases of scientific emergence like that in Figure 7.1. For example, the entities in such scientific examples are compositionally related, rather than being wholly distinct individuals, so can causation hold downwardly between the emergent whole and its lower-level parts?

In contrast, a smaller group of scientists and philosophers has explicitly argued that FDR is best understood as a *sui generis* relation different from both causal and compositional relations.

Elsewhere I have coined the term "machresis" (Gillett (2016)) for this new type of relation. But a range of philosophers espouse such a relation, whatever we call it, including Van Gulick (1993), Gillett (2016), and Stump (2012), and also scientists like Freeman (2000) or Laughlin (2005), among others, are plausibly interpreted as espousing this relation:

> *Machresis* – FDR is a non-causal and non-compositional determinative relation that holds "downwardly" from the emergent whole to its parts or between their properties or activities.

The main challenges facing proponents of machresis are, first, to articulate its nature and defend the coherence of this relation and, second, to defend its actual existence, using empirical evidence from concrete scientific cases.

My goal in this chapter is simply to briefly outline and then assess these two accounts of the deeper ontological character of FDR, in downward causation and machresis, having alerted the reader to the other alternatives noted earlier. In this manner, the reader will then have a sense of the terrain concerning a foundational issue confronting contemporary emergentism in the sciences.

I start, in Part 1, by briefly looking at compositional explanations and some features of their compositional relations, since the characteristics of composition constrain any account of FDR because all scientific emergents are composed entities. Part 2 then outlines the positions that take FDR to be "causal". I highlight how different pictures of downward causation and FDR result, depending upon whether we take "causation" to be a "thick" productive relation involving an activity or to be an ontologically "thin" relation of manipulability. I assess each of these views of FDR in Part 3, and I show that there are foundational reasons to believe it is impossible for FDR to be *either* a productive *or* manipulability relation – hence suggesting FDR cannot be a causal relation.

Having found a real need for an alternative to downward causation, in Part 5, I turn to accounts of FDR as a machretic relation. I show that such views avoid the difficulties of downward causation by being compatible with the features of composition, but I highlight the challenges, and extra ontological commitments, involved with machresis. I also note how when we synchronously have machresis acting downwards, alongside compositional relations upwards, then we routinely have a benign form of downward causation existing over time – hence potentially explaining why so many writers think downward causation is involved in scientific emergence even though FDR is not itself a relation of downward causation.

## Part 1: compositional explanation in the sciences

To underpin our discussion, we need examples of compositional explanations to get a grip on the nature of such models and the relations they posit, since scientific emergence is found in such cases. I therefore look at a couple of examples of compositional explanation from cell and molecular biology, in the section "Two species of the compositional explanation/model". Then in the section "Some features of compositional relations" I use this work to outline features of composition and how they provide constraints on any adequate account of FDR.

### *Two species of the compositional explanation/model*

Our compositional molecular explanation of cellular protrusion takes the following form. The cell is filled with monomers of globular actin ("G" actin) in the form of unchained actin molecules. One important feature of actin is that it can polymerize swiftly in long filaments ("F" actin). As the model

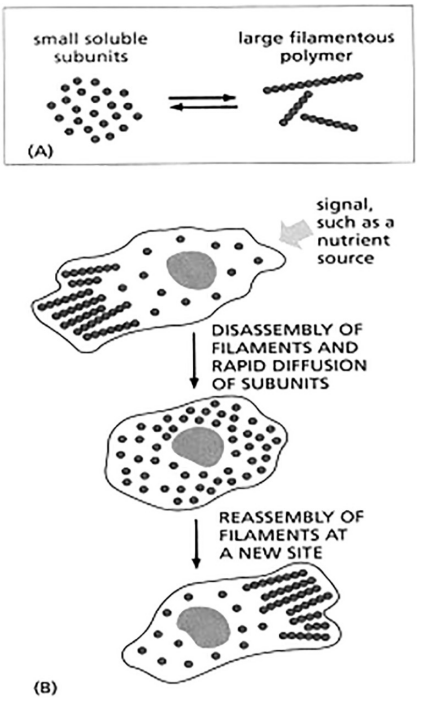


*Figure* 7.2 Diagram of the molecular basis of cellular protrusion

in Figure 7.2 frames, we consequently explain the protrusion of the cell, an activity of a whole, using directed polymerizations of monomers of G actin into many filaments of actin that press on the lipids in membrane (i.e. using activities of parts). Basically, scientists posit a compositional relation, what I term an "implementation" relation, between the activities of the parts and the activity of the whole. In the assumed compositional context, this compositional relation provides a reason for the existence of the activity of the whole – hence allowing an ontic explanation of it.

It is worth looking at another species of compositional explanation, so consider those that take a property, rather than activity, of a whole as their explanandum. As an example, consider the historically important explanation of the mass-energy of wholes using a compositional relation to the combined mass-energy of their parts at a certain level. For example, the mass-energy of a cell is explained by its being composed, or "realized", by combining the mass-energies of its parts in its proteins, i.e. properties of its parts. There are still further species of compositional explanation, but just using these species, and concrete cases of them, we can highlight some general characteristics of compositional relations.

## *Some features of compositional relations*

Our examples highlight that there are plausibly a number of compositional relations posited in compositional explanations/models – part/whole relations between individuals, as well as realization between the properties of parts and wholes, and implementation between the activities of parts and wholes. Our cases also highlight common characteristics of these compositional

relations. Among their shared features, first, we should note that compositional relations are synchronic, since their relata exist at the same time, and that relevant changes to the relata immediately or synchronously accompany each other. For example, increasing the mass-energy of parts synchronously increases the mass-energy of the whole, and vice versa.

Second, we should mark that the relata of compositional relations are in some sense the same, though the relation is weaker than identity. We usually have many components and one composed entity. The cell is in some sense the same as the many proteins, and the mass-energy of the cell is in some sense the same as the combined mass-energy of the many proteins. However, the sameness here cannot be identity – many entities cannot be identical to one entity. Furthermore, qualitatively different entities cannot be identical, and the cell or its mass-energy differs from any protein or its mass-energy.

Fortunately, the sciences do provide more concrete manifestations of this sameness. For example, we have seen how the mass-energy of a whole, like the cell, just is the combined mass-energies of its constituents at some level. Here we see a concretization of the characteristic sameness of the relata of compositional relations in the sciences.

These latter features underlie what I have elsewhere dubbed the "ontologically unifying power" of compositional explanations – when successfully supplied these explanations highlight compositional relations whose existence shows that what we previously thought were independent entities are in some sense the same. There are many other features of compositional relations in the sciences, but these few noted characteristics will suffice for our work here.[4]

It is presently a philosophically contentious issue what the deeper character of such relations of scientific composition actually is, and there are various competing accounts.[5] Some views even take composition to be a causal, or causation-like, relation. However, all these accounts need to accommodate the features just outlined which we find in actual compositional explanations. In these debates, the account I favor takes scientific composition to be a "joint role-filling" relation where a team of component entities together fill the role of, and provide a reason of existence for, some composed entity in a compositional context (Gillett (2016)). However, in my argument below I do not rely on this account, but it will be useful to have a view of composition in hand to highlight claims about the nature of machresis later in the chapter.

Scientific emergentism is committed to emergent entities being composed, so when we have scientific emergence, we always synchronously have the upward compositional relation between components and emergent entity as Figure 7.1 shows. But on top of such composition, the scientific emergentist takes the foundational determinative relation to synchronously hold from the composed entities to their components.

Clarifying some of the features of compositional relations is therefore important because FDR must be compatible with such relations and their singular characteristics. Since scientific emergence involves compositional relations between entities holding upwardly *alongside* FDR holding downwardly between these same entities all at the same time. In the coming sections, I examine how accounts of FDR as downward causation, and then machresis, fare with this important constraint.

## Part 2: downward causation as the foundational determinative relation of scientific emergentism

Various scientific emergentists and philosophers have claimed FDR is downward causation.[6] In the section "Two species of downward causation and FDR as direct downward causation", I make this proposal concrete and articulate the specific type of downward causation that FDR

must apparently be. I also separate out two distinct theories of causation, since I seek to remain neutral between these accounts and examine what downward causation, and FDR, would be like under each in the sections "FDR as an activity of an emergent whole on its parts" and "FDR as a manipulability relation between an emergent whole and its parts".

## *Two species of downward causation and FDR as direct downward causation*

It is common to talk of "downward causation" in the sciences, since there are techniques that scientists use to illuminate causal relations, and these are often applied across the properties or activities of compositional levels of parts and wholes. On top of this picture, we need to add the scientific emergentist's commitment to FDR. It therefore helps to start by filling out what Langton's diagram looks like under the view that FDR is downward causation in a wider picture of what happens over time as well as at various times.

In Figure 7.3, we now have two times represented and the causal relations over time that result from the emergent whole and its parts in later effects alongside the causal relations now taken to hold at each of these times between parts and wholes.

At the first time, in Figure 7.3, the parts s1-sn compose the whole s*, the properties of P1-P3, of s1-s3, compose the property F of s* and the activities of s1-s3 compose any activities of s*. Furthermore, at this time, through FDR, the emergent whole causally determines its parts and/or properties have certain powers that we can call "differential powers".

Over time, by time $t_2$, property F of s* causes effect G in s** at the level of wholes. And as the parts behave as a result of their differential powers, the parts causally bring about certain effects, call them Pz, in other individuals, s′1-s′3, at the level of parts. We therefore have "horizontal" causal relations between wholes and parts, respectively. Although not represented on the diagram, for simplicity, the activity of the whole s* is composed by activities of its parts in s1-s3, In addition, however, we should note that we also appear to have a "diagonal" causal relation of some kind from the emergent whole s*, at $t_1$, to the effects Pz at the level of parts at $t_2$, since without the emergent whole and its property F, the parts would not result in Pz – this is represented with the downward diagonal arrow.

The point I want to highlight in this picture of FDR as downward causation is that it is left committed to two different kinds of causal relations, including two kinds of downward causation: a "vertical" downward causal relation at $t_1$ between the emergent whole and its parts (or their properties or activities) and a "diagonal" downward causal relation from $t_1$ to $t_2$ between the emergent whole and later effects at the level of the parts. And it is important to notice that these two types of downward causal relations have importantly different features.

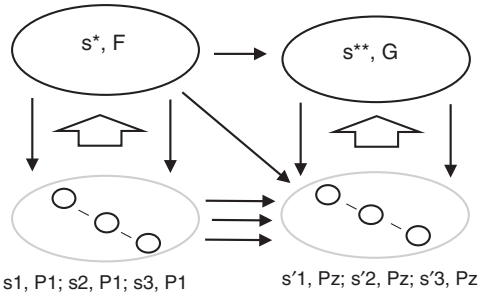


*Figure 7.3* Diagram of a scientific emergentism taking FDR to be a causal relation. The enclosed arrows are compositional relations and the other arrows are causal relations.

To bring this out, let us call "Direct" a relation of causation (or manipulability) between property/activity X of one individual and property/activity Y of another individual, where X and Y are in some sense the same, the relation between X and Y is synchronous, and the relation involves synchronous changes in X and Y. In contrast, let us call "Mediated" a relation of causation (or manipulability) between property/activity X of one individual and property/activity Y of another individual, where X and Y are wholly distinct, the relation between X and Y is temporally extended, and involves changes to X and Y that take time.

Applying this rough distinction between Direct and Mediated causation, we see that because FDR is a synchronous relation between compositionally related individuals or their properties/activities, it is a Direct causal relation. In contrast, the "diagonal" relation from the emergent whole to later effects at lower levels is plausibly a Mediated causal relation, since it is diachronic and between entities that are not in some sense the same. Later I return to the differences between Direct and Mediated downward causation, but from this point on I assume causal accounts of FDR are attempts to frame a Direct causal relation.

## *FDR as an activity of an emergent whole on its parts*

Philosophers continue to differ markedly over the nature of causation and endorse a variety of accounts of this relation. I cannot examine all of these proposals, nor do I wish to take sides about what "causation" is either in scientific practice or ultimately. So I look at accounts of FDR framed using the two most prominent families of accounts of "causation" (Hall (2004)) in ontologically "thick" productive and ontologically "thin" manipulability accounts.

Let us start with what FDR as downward causation looks like under accounts treating causation as an ontologically thick relation of what I term "production". As my exemplar of such positions, I focus on views that take "production" to be an activity of an individual, deriving from its powers, that results in and explains certain effects.

This view of FDR takes it to be an activity of the emergent whole that synchronously acts upon its parts to change them. Since we have good empirical evidence that all activities of wholes in nature involve transfer of energy or mediation of force, then there would be a synchronous transfer of energy between the emergent whole and its parts and/or a synchronous exertion of a force between them. We thus have a picture of FDR as an ontologically rich, productive relation between an emergent whole and its parts at a time.

## *FDR as a manipulability relation between an emergent whole and its parts*

On the other side, we have ontologically thin accounts of "causation" like counterfactual and related treatments. Here, given its widespread popularity and connections to scientific practice, I take as my exemplar so-called "interventionist" frameworks that treat "causation" as a relation of manipulability (Woodward 2003, 2015). Within the interventionist framework, causation between X and Y is taken to be a relation of "manipulability" – roughly put, if you can wiggle X and thereby wiggle Y, then we have manipulability between X and Y.

The strength of this approach is that Y is taken to be manipulable by X if we can have an ideal intervention on X with regard to Y where a careful and sophisticated set of conditions for an ideal intervention is then constructed to exclude common causes of X and Y, accidental correlations with Y, and so on. One encouraging sign for those wanting to understand FDR as a manipulability relation is that writers like Craver (2007) have already argued that we standardly have a relation of mutual manipulability between composed and component entities in compositional

explanations. So the scientific emergentist would be proposing an account of FDR mirroring this account of composition.[7]

Here Craver (2007)'s adaption of the notion of an "ideal intervention" to apply to such "vertical" relations seems most appropriately used when framing such an account of FDR:

> An *ideal* intervention I on [X] with respect to [Y] is a change in the value of [X] that changes [Y], if at all, *only via* the change in [X]:
>
> (I1c) the intervention I does not change [Y] directly;
> (I2c) I does not change the value of some other variable [Z] that changes the value of [Y] except via the change introduced into [X];
> (I3c) that I is not correlated with some other variable M that is causally independent of I and also a cause of [Y];
> (I4c) that I fixes the value of [X] in such a way as to screen off the contribution of [X]'s other causes to the value of [X].
>
> *(Craver (2007), p. 154)*[8]

The resulting position claims that FDR is a manipulability relation, and so cases involving FDR will satisfy these conditions on an ideal intervention. We do not have space to go through the various conditions on an ideal intervention, but let me highlight the first condition that X is an ideal intervention on Y only if the intervention on X does not directly change Y. It also is worth emphasizing that the notions of an ideal intervention and manipulability are both technical notions defined by such frameworks.[9]

## Part 3: foundational problems for FDR as downward causation

It is striking that compositional explanations have ontologically unifying power but causal explanations do not. There are also apparent mismatches in the features of FDR and causation. However, I put such concerns to one side and instead look carefully at foundational concerns about our two theoretical treatments of FDR. In the section "Assessing FDR as a productive relation", I present reasons to think it is physically impossible for scientific wholes and parts to productively interact – and hence impossible for FDR to be a productive relation. Then in the section "Assessing FDR as a relation of manipulability", I present an argument that it is impossible for a Direct causal relation to satisfy the first condition for an ideal intervention, and hence impossible for FDR to be a manipulability relation.

### *Assessing FDR as a productive relation: an energetic argument for physical impossibility*

A variety of arguments can be given to show that scientific wholes and parts do not productively interact, but let me focus on one centered on mass-energy. In giving this argument, following our successful compositional explanations, I assume the mass-energy of a whole at a time just is the combined mass-energy of its parts at a certain level at that time. Thus, the mass-energy of a cell at a time just is the combined mass-energy of its constituent proteins at this time. And I also assume, again as a result of our empirical findings, that all activities of scientific parts and wholes involve transfer of energy. With these assumptions in hand, let me outline a reductio ad absurdum argument that shows it is physically impossible for a scientific whole to engage in a productive relation with its part, or vice versa.

Consider the cell and a molecule of actin. For the sake of reductio, assume the cell, s* (which is the whole here), productively acts on a molecule of actin, s1 (a part of s*), and changes it – thus framing the picture of FDR as a downward causal relation. Assume the cell transfers energy T to the molecule through this activity. But we know the mass-energy of the cell equals the combined mass-energy of the proteins s1-sn, including our actin molecule s1, and let this equal N. So, the mass-energy of the cell is N. But given the transfer of mass-energy through the productive relation we are assuming FDR to be, from s* to s1, we can conclude the mass-energy of the cell is (N-T). In similar fashion, given this transfer, we can also conclude that the combined mass-energy of the parts, s1-sn, is (N+T). But assuming the cell's mass-energy is the combined mass-energy of the parts, we can thus also conclude that the mass-energy of the cell is (N+T). So we may conclude that the mass-energy of the cell is, and is not, (N+T).

We thus have a contradiction, and the premise that is the most plausibly the candidate for being false is that the scientific whole productively acted upon its own part. So we have a reason to conclude that scientific wholes cannot productively act upon their parts. Consequently, we have reason to conclude that the foundational determinative relation taken by scientific emergentism to hold between scientific wholes, and their parts, cannot be a productive relation.

## *Assessing FDR as a relation of manipulability: an argument for the impossibility of certain ideal interventions*

Let us turn to critically assessing accounts of FDR as an ontologically "thin" relation of manipulability. To see the worry here, let us focus once more on the mass-energy of the emergent whole and its parts, that is, a relation between a property of a whole and properties of its parts, though the same point goes through for compositional relations involving other properties or activities.

Notice that if we intervene to alter a property of the emergent whole that bears FDR to some property of a part, where these properties are compositionally related, then the change in the latter property will be synchronous with the change in the former. For example, if we intervene to change the mass-energy, call it X, of a cell by adding or removing energy to this whole, then this directly changes the energy, call it Y, of at least one part – for the energy of the whole just is the combined energies of the parts. But this consequently prevents satisfaction of the condition for an ideal intervention highlighted earlier, that is, Craver's (I1c), for the intervention on X directly changed Y. But having an ideal intervention is a requirement for having a manipulability relation, so we see that FDR cannot be a manipulability relation.

This type of argument is generally applicable to show that *Direct* causal relations cannot be manipulability relations, for the synchronous character of the changes in their relata precludes satisfaction of the technical requirements for an ideal intervention and hence for the existence of manipulability. We thus see that there is good reason to conclude that FDR cannot be a manipulability relation, since FDR holds synchronously between compositionally related entities.

In contrast, it is worth marking that this argument does not apply to *Mediated* causal relations even when relating properties of wholes and parts. For example, we can press on one side of a cell, changing its shape, X, and this synchronously affects the position, Y*, of a protein that is a part of the cell which composes X. Further, assume the moved protein then productively changes the position Y of a distinct protein where Y does not compose the cell's shape X. Notice that the intervention on X with regard to Y* is not ideal, since it is a Direct causal relation. But the intervention on X with regard to Y is plausibly ideal because, as a Mediated causal relation, a change in Y is not directly produced by the intervention on X – crucially X and Y are not compositionally related properties.

One diagnosis of the appeal of downward causation as an account of FDR is that its proponents have not sufficiently appreciated the features of FDR, or the differences between Direct and Mediated causation. Crucially, the form of causation that has the right features to be FDR cannot involve a relation of manipulability, whilst the species of manipulability often holding between properties/activities of wholes and parts does not have the characteristics of FDR. We can thus see how proponents of FDR as downward causation could easily have fallen into the mistake of thinking it is a viable option.

## Part 4: machresis as the foundational determinative relation of scientific emergence?

Although widely popular, we have now found foundational reasons to think that FDR cannot be downward causation. Fortunately, there is another option for scientific emergentism: taking FDR to be a non-causal, and non-compositional, relation of machresis that holds alongside composition. Assuming that productive relations can never hold between parts and wholes, given our earlier argument, we get the type of position outlined in Figure 7.4.

At $t_1$, we have the upward compositional relations between s1-sn and s*, as well as between their properties and activities, but now we assume we also have the downward machretic relation(s) between some of these compositionally related entities. Over time, we have horizontal productive relations, and a diagonal downward relation of manipulability in a Mediated causal relation – hence highlighting how FDR as machresis results in benign, Mediated downward causation.

This position does not face the type of problems we found with the picture of FDR as downward causation because machresis is like composition in being a synchronous relation between entities that are in some sense the same and it does not involve transfer or energy or mediation of force. However, we know machresis is not a compositional relation because the activities of wholes are such that they cannot fill the roles of their parts – hence stopping them from being joint role-filling relations. Instead, machresis is more plausibly thought of as a role-molding or role-constraining relation which highlights how machresis plausibly involves constraint, reduction in degrees of freedom, or certain kinds of boundary conditions emphasized by the writers noted earlier.

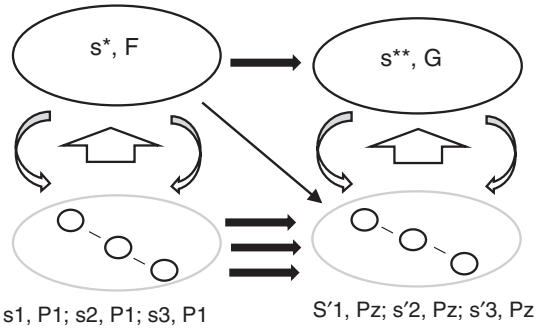


*Figure 7.4* Diagram of a scientific emergentism taking FDR to be a machretic relation. The straight enclosed arrows are compositional relations, while the curved enclosed arrows are machretic relations. The thick black arrows are productive relations, and the thin arrow is a manipulability relation.

Under such an account of FDR as machresis, emergent wholes, properties, or activities would be determinative, since the emergent entities machretically determine that their parts have certain differential powers. So "Parts behave differently in wholes" and hence the "Whole would be more than the sum of its parts" – hence securing key claims of scientific emergentism.

As well as such benefits, we need to note some costs of such a view. First, the position accepts both manipulability and production over time along with machresis and composition holding at a time – so embracing a number of relations. Second, the view endorses what I elsewhere term the "Conditioned" view of aggregation (Gillett (2016)) by taking parts in certain aggregations to have differential powers that they would not have if laws in simpler systems were exhaustive. However, both of these commitments are plausibly central to scientific emergentism, rather than deriving from acceptance of machresis.

More importantly, we should mark the two-pronged critique that proponents of machresis need to meet. First, philosophers and scientists argue against the very coherence and possibility of machresis. So a central task of those attracted to machresis is to show it is coherent. However, promising efforts have been made to meet this challenge.[10] Further theoretical work is also needed to simply better understand machresis – for instance, illuminating how, and why, machresis holds in concrete cases.

Second, philosophers and scientists routinely contend that there is no empirical evidence of anything like machresis in nature. So alongside the theoretical work just noted, scientific emergentists need to supply interpretations of compositional explanations defending the existence of machretic relations in these examples. Once again, encouraging efforts have been made in this task. From superconductors to slime mold, working scientists like Anderson, Laughlin, Freeman, and many others have offered a parade of such cases, though more work arguably needs to be done to precisely support their interpretations.

## Conclusion

My final conclusion is that scientific emergentists need to give more careful attention to their view of the foundational determinative relation that is at the heart of their positions. Although popular, I have argued that there is *not* (nor could there be) the Direct downward causation required for FDR to be a causal relation. If we take causation to be a "thick" productive relation, we face arguments that scientific wholes and parts cannot bear productive relations. On the other hand, if we take causation to be a "thin" manipulability relation, then we find that it is impossible for the Direct downward causation needed for FDR to satisfy the conditions for an ideal intervention and hence to be a manipulability relation.

Foundational difficulties thus face the common view that FDR is a relation of downward causation. In contrast, taking FDR to be relation of machresis, in a non-causal and non-compositional relation of role shaping or role constraining, avoids such difficulties. As we have seen, when we have FDR as a synchronous machretic relation, then we also have Mediated downward causal relations over time as a result. Substantive work needs to be done to show that machresis is coherent and that empirical evidence supports the existence of machresis in concrete cases. But it bears emphasizing that there is promising work on both of these fronts in contrast to what appear to be intractable foundational problems in understanding FDR as a causal relation.

## Notes

1 Anderson (1972, 1995), Freeman (2000), and Laughlin (2005).

2 In Gillett (2016) I term this "Strong" or "S-emergence". In this chapter, wherever I talk of "emergence", unless noted, I mean such scientific emergence.

3 All of the candidates for FDR can be taken to hold between composing individuals, or properties, or activities. For simplicity of exposition, I focus on individuals in parts and wholes, but FDR can also be taken to hold between a composed emergent property or activity and its composing properties and activities.
4 Gillett (2016), chapter 2, gives a fuller, but not complete, list of such features.
5 See Aizawa and Gillett (2016) for an overview of these debates. The existence of treatments of scientific composition as causation-like means that potentially there are views where we have causal relations in both upward and downward directions between the whole and parts. In my discussion, I simply focus on views solely taking FDR to be causal. But in the notes I highlight how the arguments I outline later also undercut positions that take *both* FDR *and* composition to be causal or causation-like.
6 For earlier examples, see Campbell (1974) or Sperry (1986), and for more recent examples see Andersen et al. (2000).
7 The problems I raise later for taking FDR to be a manipulability relation also undermine taking composition to be a manipulability relation.
8 I have changed the variables in the passage to X and Y to be consistent with the rest of my discussion.
9 Woodward (2003, 2015) has a slightly different set of conditions than Craver's (2007) adaption, but the first condition I focus on here is the same.
10 See, for example, Gillett (2016), chapters 7 and 8.

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