Scientific Emergentism and the Mutualist Revolution: A New Guiding Picture of Nature, New Methodologies and New Models

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> The world we actually inhabit, as opposed to the happy world of modern scientific mythology, is filled with wonderful and important things we have not yet seen because we have not looked… The great power of science is its ability, through brutal objectivity, to reveal to us truth we did not anticipate. (Laughlin (2005), p. xvi)

The guiding picture of nature to which we subscribe—what we take the ontological structure of nature to be in a broad sense—configures not just what kinds of scientific models and explanations we offer, but also what phenomena we even seek, and recognize, in nature. In our opening passage, Robert Laughlin, echoing other scientific emergentists like Ilya Prigogine, tells us that we have routinely overlooked all manner of phenomena that did not fit the guiding picture of nature pressed by scientific reductionism. For recent empirical findings, emergentist like Laughlin and Prigogine contend, show that the picture of scientific reductionism is in fact a misleading "myth".[1]

Still more exciting, scientific emergentism offers a new guiding picture that allows us to finally see many natural phenomena and provides novel models/explanations that potentially allow us to understand them. The result, over the last few decades, is arguably a revolution in the sciences built around adoption of a new view of the relation of parts and wholes, and hence of the structure of nature itself. The pioneering scientists pressing this view, calling themselves "scientific emergentists", include physicists like Laughlin or Philip Anderson, chemists such as Prigogine, biologists including Denis Noble, neuroscientists like Walter Freeman, and many in systems biology or the sciences of complexity.[2]

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[1] See Prigogine and Stengers (1984), and Prigogine (1997), for Prigogine's own interesting discussion of such ontological "myths".

[2] Anderson (1972), Freeman (2000), Laughlin (2005), Noble (2006), and Prigogine (1997).

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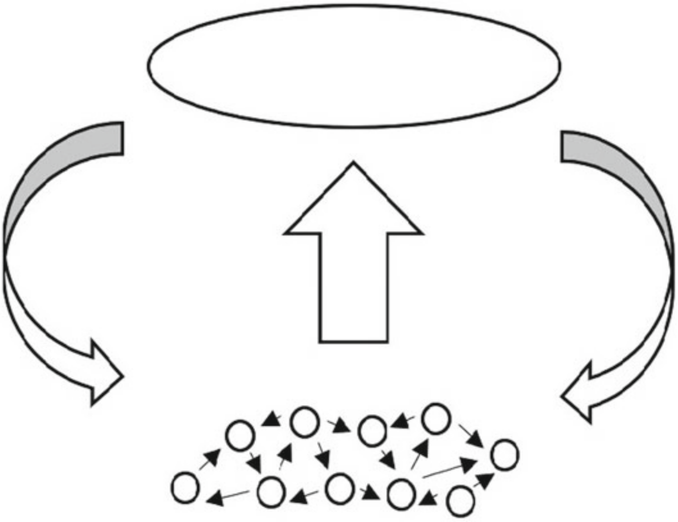

Fig. 1 The complexity researcher Chris Langton's famous diagram of the scientific emergentist's Mutualist view of nature. (Redrawn from Lewin (1992))

At the heart of their positions, these researchers endorse what I have elsewhere termed "Mutualism" whose core idea is framed in Fig. 1. Under the Mutualist picture, it continues to be the case that certain complex wholes (and their activities and properties), like the one at the top of the diagram, are taken to be fully composed by organized parts (and their activities and properties) shown at the bottom—and hence we have compositional relations upwards from parts (and their activities and properties) to the whole (and its activities and properties). However, the foundational change under Mutualism is to accept that sometimes we also have a downward determinative relation from the whole (and its activities and properties) to its parts (and their activities and properties) depicted by the downward curving arrows. Consequently, we have *both* upward *and* downward determination, and hence *mutual* determination between parts and whole—hence the "Mutualist" tag for the position. The result is a new picture of nature with all manner of exciting implications.

Simply appreciating Mutualism has profound theoretical and practical implications in the sciences. Elsewhere I have sought to provide a detailed treatment of Mutualism and the wider debates over reduction and emergence in which it figures (Gillett, 2016a). In this paper, my goal is narrower. I simply seek to provide an accessible account of scientific emergentism and its key claims. To this end, I briefly sketch the background to scientific debates over reduction and emergence, but my primary focus is on outlining the core ideas of Mutualism, the new guiding picture of nature that results, and hence the novel methodologies it offers and the new models its provides in concrete scientific cases.

To start, I sketch two connected waves of scientific findings about compositional relations that drive our present research as well the debates over reduction and emergence. The first wave of findings, outlined in Part 1, stretching from the Scientific

Revolution onwards, was to provide what I term “compositional” models and explanations of wholes (and their properties and activities) using compositional relations to parts (and their properties and activities). Thus, for instance, we explain the contraction of a muscle by a compositional relation to moving protein filaments that compose it. Or we explain the mass of the muscle using a compositional relation to the masses of the cell’s that are its parts.

As I highlight, all sides in the sciences accept the need to search for, and provide, such compositional explanations in what I term “everyday reductionism”. And the success of this methodology in providing compositional explanations/models, and the advent of new techniques, has more recently allowed a second wave of usually quantitative scientific findings, outlined in Part 2, about the activities of the parts we find in wholes. This more detailed, and precise, understanding of the behaviors of parts in wholes has led to a range of what I term “Challenging Compositional Cases” where we cannot presently understand the behaviors of the parts in various wholes using existing resources, including accounts and models given of such parts in simpler systems. Across examples in a range of sciences, from super-conductors to populations of neurons, Challenging Compositional Cases are now at the cutting edge of ongoing scientific inquiry.

I briefly outline, in Part 3, how everyday reductionism, and the provision of compositional explanations, has been argued to support the stronger position I term “scientific reductionism”, espoused by researchers such as the physicist Steven Weinberg, biologists like Francis Crick, Richard Dawkins or E.O. Wilson, and many others.[3] Scientific reductionists provide reasoning that, they claim, shows reflection on compositional explanations leads from everyday reductionism to their more robust scientific reductionism position. I detail the guiding picture of nature that results under scientific reductionism, one where there are *nothing but parts,* and collectives of them, but where higher sciences are needed to study collectives of parts. I highlight how this a picture under which the ultimate parts are the only determinative entities in nature and the laws about them are the only fundamental laws—thus implying only fundamental physics illuminates fundamental phenomena and fundamental laws of nature.

Against this empirical and theoretical background, in Part 4, we can finally appreciate the core ideas of scientific emergentism in its Mutualist position that allows a whole, and its parts, to be mutually determinative. This picture grows from the findings of everyday reductionism, and Challenging Compositional cases, about the behaviors of the parts in wholes. Crucially, Mutualism accepts that “Parts behave differently in wholes”, but this then allows the scientific emergentist to argue that “Wholes are more than the sum of their parts” because such wholes sometimes downwardly determine their parts. Furthermore, I note how appreciating Mutualism shows the key parsimony argument of scientific reductionism is invalid, hence blocking the main theoretical reasons commonly used to dismiss “emergence”.

Perhaps more importantly, I then detail how, as well as theoretical implications, Mutualism has substantive import for scientific practice both globally and locally.

[3] Crick (1966), Weinberg (1994, 2001) and Wilson (1998).

To begin, in Part 5, I outline how Mutualism globally underpins a new guiding picture of nature sharply contrasting in its practical import with that of the scientific reductionist. For example, I detail how this new Mutualist picture accepts that there are many compositional levels of parts and wholes in nature to explore, rather than just parts and collectives of them. And how Mutualism opens up the possibility of fundamental phenomena, laws and research at many of these levels of nature, and hence as the focus of many sciences beyond physics, rather than just at the level of ultimate parts.

Moving from the global to the local, in Part 6, I sketch how Mutualism offers a new class of "Mutualist" models and explanations positing relations of whole-to-part determination that offer help in Challenging Compositional Cases and other ongoing investigations. I highlight how Mutualist models and explanations *supplement* causal and compositional models, hence adding to everyday reductionism rather than burning it down. And I note that researchers are now exploring whether such Mutualist models are successful, or even the best models available, in various ongoing cases from superconductors to neural populations.

1 The Wave of Compositional Explanations from the Scientific Revolution Onwards

Compositional explanations have been one of the main engines of the sciences since the Scientific Revolution, transforming our understanding of nature. Philosophers of science have used a range of terms for compositional explanation, including "reductive explanation", "functional explanation" or "constitutive mechanistic explanation".[4] Let us consider just a few examples of compositional explanation drawn from physiology, cell biology and molecular biology to appreciate their character.

In response to the question "Why did the muscle contract?" two good answers, in certain contexts, are based around the model in Fig. 2 and are "The cell fibers contracted" or "The myosin crawled along the actin". This is the one species of compositional explanation widely acknowledged by philosophers of science where we explain *an activity* of a whole using a compositional relation to activities of parts in what are often termed "constitutive mechanistic explanations" and which I term "Dynamic" compositional explanation.[5] We explain the muscle's contraction at some time using a compositional relation to the contraction of various cells at that time. The cells are inter-connected, or "organized", so as each contracts it pulls on the cells

[4] Though neglected, there has been philosophical work on compositional explanation that goes back at least to early work by Fodor (1968) and Dennett (1969), through Wimsatt (1976), down to more recent work such as Bechtel and Richardson (1993), Glennan (1996), Machamer, Darden and Craver (2000) and Craver (2007), amongst many others. See Aizawa and Gillet (2019) for an outline of some of the various species of compositional explanation.

[5] Aizawa and Gillet (2019).

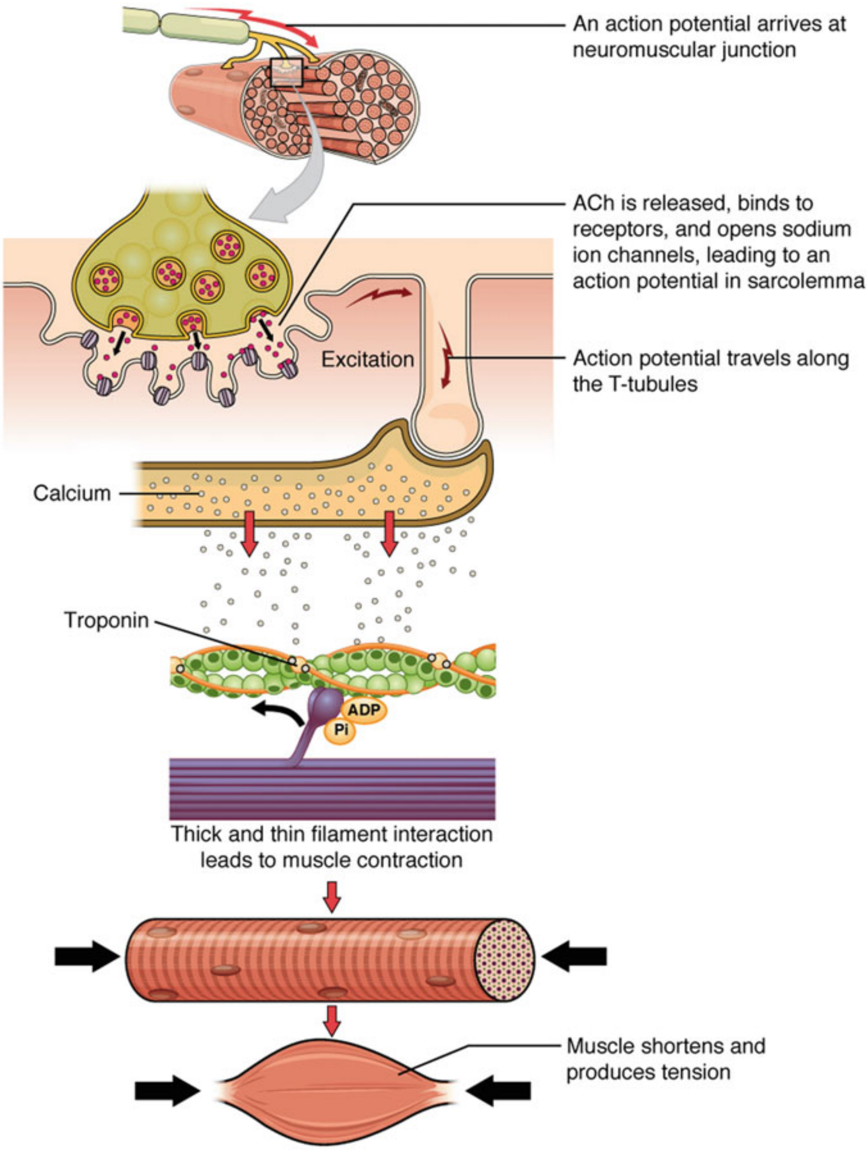

Fig. 2 A textbook diagram of the sliding filament model of muscle contraction and a Dynamic compositional model. (From Betts (2013), Chap. 10, Sect. 10.3, Fig. 1)

to which it is connected and which are also contracting. Hence the contracting cells compose (or what I term "implement"), and explain, the muscle's contracting.

There are plausibly other species of compositional explanation. What I have elsewhere termed a "Standing" compositional explanation explains *a property* of a whole using a compositional relation, what is termed "realization", to properties of parts.[6] For example, in response to the question "Why is the muscle strong?" one could answer "Because the cell's each have a certain strength" or an answer focused on the properties of proteins. For we explain the strength of the muscle, a property of a whole, using compositional relations of realization to properties of its parts at the cellular and molecular levels.

Lastly, we should note that when asked "What is a skeletal muscle?" two good answers (amongst others) in the relevant contexts, are "Bundled muscle fibers", as Fig. 3 highlights, or "Organized proteins". Here the explanadum is *a certain whole*, i.e. an individual, the explanans is some group of parts (at a certain "level") and the backing relation is the part-whole relation between these individuals. I term this an "Analytic" compositional explanation where we explain a whole itself using a compositional relation to individuals that are parts.

All of these explanations are what I shall term "ontic" explanations that work by representing an ontological relation between entities in the world, the "backing relation" of the explanation, where the nature of this relation drives these explanations. In addition, these explanations are also all backed by compositional, rather than causal, relations, since their backing relations all share common ontological features lacking in causal relations. For example, amongst other singular features, their backing relations are all synchronous relations, between entities that are in some sense the same and which involve synchronous changes in their relata.[7] So we can see that these are not causal explanations.

As our examples begin to highlight, all of the species of compositional explanation about a common phenomenon are plausibly systematically integrated with each other.[8] Furthermore, such explanations are systematically integrated with the related causal explanations, about connected phenomena, that philosophers of science term "etiological mechanistic explanations", amongst others. It is important to remember this point, since it highlights how scientists often seek, and provide, various integrated causal and compositional models/explanations in tandem about a certain state of affairs in nature.

As researchers piled up compositional explanations of phenomena across all levels in nature, scientists came to accept that everything in nature is composed by the entities of physics and hence to endorse this as a guiding picture of the structure of nature—the view that all individuals, activities and properties are either entities of fundamental physics or composed by the entities of fundamental physics. Under this

6 Aizawa and Gillet (2019).

7 Elsewhere I have highlighted still further differences between the features of such compositional and causal relations. See Gillett (2016a), Chap. 2, (2016b), (2020) and (Forthcoming), Chaps. 1–3.

8 See Gillett (Forthcoming) for a more detailed discussion of such integration. We thus have another example of what Mitchell (2003) terms "integrative pluralism" in multiple, but integrated, models.

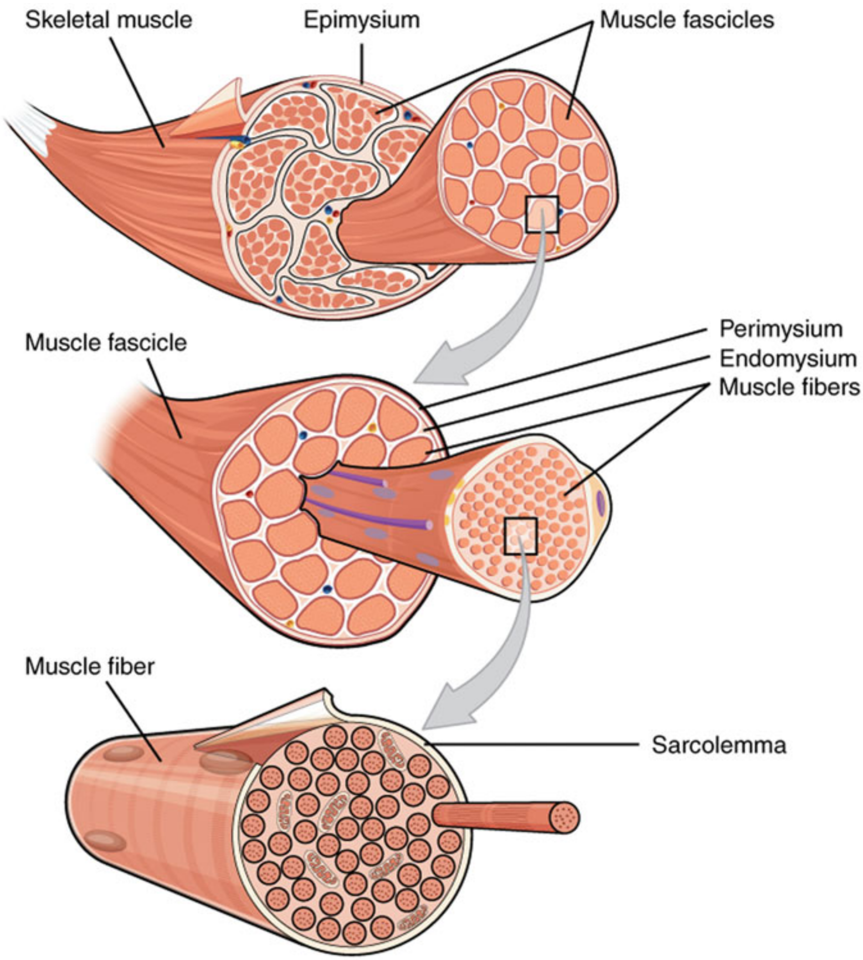

Fig. 3 A textbook diagram of the composition of a skeletal muscle at tissue and cellular levels, and hence a multi-level Analytic model of it. (From Betts (2013), Chap. 10, Sect. 10.2, Fig. 1)

picture, we have both wholes and their parts, as well as their activities and properties, which are all compositionally related in various (local) compositional levels down to the entities of physics. Once we endorse this guiding picture it also entails obvious methodological guidance–search for compositional explanations of all entities in nature! Carefully note, however, that such guidance does not exclude the existence of, or need to provide, other models/explanations as well.

The search for compositional explanations was at the cutting-edge of twentieth century science and furnished the first great wave of empirical findings I wanted to highlight in a huge array of compositional explanations across the sciences and the levels of nature from chemistry on through to neuroscience and physiology.

As I detail below, all working scientists now acknowledge, and seek for, such compositional explanations/models.

It is therefore important to clarify some terminology. In the sciences, but also amongst some philosophers, common terms for a compositional explanation are that it is a 'reductive' or 'reductionist' explanation and the term 'reductionist' is thus often simply used to refer to someone who seeks compositional explanations (Wimsatt, 2007) who is taken to be pursuing a 'reductionist methodology'. Unfortunately, as later sections make plain, on these mundane usages *both* scientific reductionists *and* opposing scientific emergentists are all 'reductionists' who all explicitly seek 'reductionist explanations' and all endorse 'reductionist methodology'!

We therefore need a better terminology, so I use the neutral term 'compositional explanation' to refer to the explanations both sides acknowledge as important and which I have highlighted in this section. When I need to refer to the weaker, and as we shall see universally endorsed, position espousing the search for compositional explanations I shall refer to 'everyday' reductionism. I use the term 'scientific reductionist' for the more substantive positions endorsed by writers, like Weinberg, Crick, Dawkins, Wilson etc., that I detail in Part 3. As we shall shortly see, distinguishing everyday reductionism from scientific reductionism is important for a variety of reasons, but the most obvious is that each supplies a different "guiding picture of nature" and hence entails very different guidance on what scientific models/explanations, and methodologies, will be successful.

2 A Second Wave of Findings about Parts: Understanding Challenging Compositional Cases

In the twenty-first century, and late twentieth century, with the advent of new experimental and theoretical techniques researchers explored a range of aspects of parts and wholes. In particular, these new techniques have yielded quantitative accounts of the behaviors of parts within complex wholes from superconductors to cells or populations of neurons. It is important to emphasize these are all cases where we have well confirmed compositional explanations and models. So the relevant wholes, and their properties and activities, are all known to be fully composed—hence there are none of the new forces or energies, or uncomposed properties, involved with the type of "emergence" that figured in scientific debates at the end of the nineteenth century and early twentieth century.

In these cases where we have new quantitative accounts of the behaviors of parts, a certain kind of situation has become increasingly common. Consider the case of the proteins that compose a eukaryotic cell discussed in detail by an interdisciplinary research team consisting of philosophers of science, in Robert Richardson and Achim Stephan, as well as prominent systems theoretic biologists in Fred Boogerd, Frank Bruggeman, and Hans Westerhoff (Boogerd et al., 2005). We have a great deal of evidence about the properties, and behaviors, of such proteins in simple systems whether in vitro or elsewhere. In addition, as Boogerd et al. highlight, we have now also collected quantitative evidence about the activities (and hence properties) of such proteins when they are actually parts of cells. Researchers like Boogerd et al. consequently argue that we can now see that the activities of the proteins in cells cannot be explained using the accounts given for them in simpler systems. That is, our quantitative account of the behaviors of these parts in cells, combined with our successful accounts of such proteins in simpler systems, together show that these parts behave differently than they would if the accounts in simpler systems were exhaustive in the whole.

Similar arguments have been given across a range of cases. For instance, Robert Laughlin (2005) plausibly makes such an argument about the behaviors of electrons when they are parts of superconductors. Laughlin takes quantum mechanics to provide a successful account of the behaviors of electrons in simpler systems and Laughlin takes us to have quantitative, and highly precise, accounts of the behaviors of electrons in superconductors. Consequently, Laughlin concludes that electrons in superconductors behave differently than they would if the accounts in simpler systems were exhaustive.

The latter are examples of what I will term a "Challenging Compositional Case" in an example where the following conditions hold:

(i) we have successful compositional accounts of a certain whole (and its activities and properties) in terms of various parts (and their activities and properties);
(ii-a) we have successful accounts of the relevant parts and their behaviors in simpler systems;
(ii-b) we now possess quantitative accounts of the behavior of these parts in the relevant whole;
and;
(iii) the behavior of the parts in the relevant whole is apparently different than it would be if the accounts of this part in simpler systems were exhaustive.

Given (iii), against the background of (i), (ii-a) and (ii-b), such cases pose an obvious challenge of explaining, or otherwise accounting for, the behaviors of the parts in the relevant wholes in such.

Such cases also highlight limitations to the guiding picture of nature suggested by everyday reductionism and it associated methodologies. This guiding picture is not wrong, since everything in a Challenging Compositional Cases is composed. But its guidance to seek for compositional explanations no longer provides resources for moving our understanding of such examples further forward. We already have compositional explanations for all the relevant entities, but the behavior of the parts in the relevant wholes still *cries out for explanation*. So everyday reductionism has hit a wall in such examples.

Two options for addressing examples like Challenging Compositional Cases loom large. On one side, one can take the behaviors of parts that are apparently unexplained by accounts used for simpler systems to be *merely apparently* problematic in an *epistemic* phenomenon—that is, an artifact of our theoretical machinery, rather than a feature of the world. In the next section, I outline why scientific reductionism is forced to adopt this deflationary option about Challenging Compositional Cases given its guiding picture of nature.

On the other side, we find the possibility that the world, rather than our theorizing, underlies the situation in Challenging Compositional Cases because parts really do have a special kind of behavior. As I outline in Part 4, this is the position of scientific emergentism. So let me frame the activities and powers we are assumed to have under this emergentist position to differentiate them from the scientific reductionist alternative. Let us say that we have what I term "differential powers" and "differential activities/behaviors" when a certain part contributes different powers, and hence behaves differently, under the condition of composing a certain whole, but where the part would not contribute these powers, and behave in these ways, if the laws applying in simpler collectives exhausted the laws applying in the complex collective.[9]

3 Scientific Reductionism, its Guiding Picture of Nature and Practical Import

Scientific reductionism grew popular in the sciences as everyday reductionism flourished in the twentieth century. For scientific reductionists, like Weinberg, Crick, Dawkins, Wilson and others, argue that reflection on compositional explanations, using a type of ontological parsimony argument, leads to their stronger position. Such arguments have long attracted thinkers. For example, ancient Buddhists reflecting on carts being composed of boards, axle and wheels concluded that we should only accept such parts and reject the existence of a further whole such as a cart. Why? Because we can putatively explain everything using the parts alone.

The advent of compositional explanations in the sciences makes such reasoning especially alluring. Consider such an argument applied in the sciences in what I term the "Argument from Composition" since it claims to be driven by the nature of composition alone. As we saw in Part 1, a good compositional explanation allows one to account for the activities or properties of a whole using the activities or properties of its parts. As we saw, we compositionally explain the muscles contracting using the movement of its constituent proteins, but not vice versa. Given the nature of compositional explanations, the reductionist concludes that our successful compositional explanations mean that we can now account for all the activities and properties of both parts and wholes using the components alone. But, given this sub-conclusion,

[9] I should note that I have defined differential powers to leave it open whether their contribution is determined by a composed entity or other component level entities. I also intend differential powers to include not only extra powers that add to the powers contributed in simpler collectives, but also contracted sets of powers excluding powers contributed in simpler collectives. There can also be mixed cases where differential powers are both added and subtracted.

the scientific reductionist claims we can then apply the so-called ‘Parsimony Principle’ in this case—that is, the principle that when we have two equally explanatory hypotheses about some phenomenon, then we should accept the hypothesis committed to fewer entities.We regularly use the Parsimony Principle in in application to scientific hypotheses and in cases of compositional explanation we have two hypotheses about what entities they concern. On one side, we have the hypothesis that we have both a whole and its parts (i.e. a muscle plus the proteins). On the other side, we have the scientific reductionist’s favored hypothesis that we have parts alone (i.e. the proteins alone). But the latter hypothesis is simpler than the former. So, applying the Parsimony Principle along with the crucial sub-conclusion, the reductionist concludes that we should only accept that there are parts alone in any case of compositional explanation or, famously, that there is really *nothing but* the parts. Similar reasoning can be run about the activities or properties of wholes to conclude there are activities and properties of parts alone.[10]

Scientific reductionism thus claims we should adopt a much starker guiding picture of nature than that of everyday reductionism. But notice that scientific reductionism is not ultimately left committed to nature as a “dust cloud” of isolated, and unrelated, fundamental parts. For the reductionist accepts compositional explanations and concludes we should only endorse the entities used as the explanans at the “bottom” of such explanations which, rather than being isolated and unrelated parts, are always *collectives* of inter-related and organized parts—thus organized, inter-related proteins (and their activities and properties), like myosin and actin in filaments, are used to explain the muscle’s contracting. Collectives are not further individuals, since “collective” is just a name for a group of inter-related parts and parts are thus still the only individuals. The guiding picture of nature, endorsed by scientific reductionism, is thus one of isolated parts *and* collectives of parts of ever increasing scales.

Appreciating its picture of nature illuminates why scientific reductionism accepts that higher sciences and their explanations are indispensable. Using statistical mechanics as his example of a higher science, Weinberg tells us that:

> The study of statistical mechanics, the behavior of large numbers of particles, and its application in studying matter in general, like condensed matter, crystals, and liquids, is a separate science because when you deal with very large numbers of particles, new phenomena emerge... even if you tried the reductionist approach and plotted out the motion of each molecule in a glass of water using the equations of molecular physics…, nowhere in the mountain of computer tape you produced would you find the things that interested you about water, things like turbulence, or temperature, or entropy. Each science deals with nature on its own terms because each science finds something in nature that is interesting. (Weinberg (2001), p.40)

Crucially, the scientific reductionist takes higher sciences to coin their own terms that refer to the larger, and larger, scale collectives of parts that they study. Scientific reductionists accept we need such higher sciences to study, and express, the truths about such collectives that cannot be expressed by lower sciences. But the only

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[10] Some of Jaegwon Kim’s famous arguments about mental causation have a related structure to the same conclusion. See Kim (1993b) and other papers in his (1993a).

determinative entities are the parts that form such collectives, and hence the only determinative laws are still solely about those parts in the simplest systems.

This last point comes into clearer focus if we look at a couple of methodological differences between everyday and scientific reductionism. First, note that everyday reductionism's mantra to search for compositional explanations applies at every level of nature using all manner of techniques. In contrast, we can see why scientific reductionists argue, under their guiding picture, that fundamental physics and its experimental machinery, like the supercollider, are specially important (Weinberg, 1994). Under scientific reductionism, fundamental physics, and its experiments, are the only one's exploring the determinative laws of nature, since the only entities that exist are the fundamental parts and hence these are the only determinative entities. Furthermore, scientific reductionism also assumes that the laws holding of such parts in the simplest systems exhaust the laws holding of such parts. Consequently, the laws holding of entities, like quarks or mesons, in the simplest systems extend to all situations and exhaust the laws holding of such entities anywhere (whether in complex or simple systems)—and hence exhaust the determinative laws of nature itself. Scientific reductionists thus conclude that special funding consideration should be given to experimental machinery of fundamental physics, like the supercollider, that illuminate these laws.

Second, connected points illuminate what scientific reductionism has to say about Challenging Compositional Cases. As we have seen, everyday reductionism offers no productive guidance to move us forward with such examples, since we have provided all the compositional explanations that we can in such cases. In contrast, scientific reductionism does offer guidance about such cases. Under scientific reductionism, the only determinative laws are those in the simplest systems and these laws exhaust the laws holding of parts in larger and larger collectives. But this means that the parts in Challenging Compositional Cases, whether electrons in superconductors, proteins in cells, or neurons in populations, only behave in ways that fall under the laws holding in simpler systems. Hence the scientific reductionist must argue that the presently inexplicable behaviors of parts in various wholes in Challenging Compositional Cases is merely an *appearance* in an *epistemic* artifact of our theorizing. For the guiding picture of scientific reductionism is committed to the laws of parts in the simplest systems exhausting the laws holding of the behavior of parts wherever they are found—and however hard it may be to understand this. Standard versions of scientific reductionism are thus left committed to a deflationary approach to Challenging Compositional Cases.

4 The Mutualism of Scientific Emergentism: The Core Idea

Rather than deflating their significance, scientific emergentism has taken our empirical findings in Challenging Compositional Cases to yield profound insights. As Laughlin tells us:

> Ironically, the very success of reductionism has helped pave the way for its eclipse. Over time, careful quantitative study of microscopic parts has revealed at the primitive level at least, collective principles of organization are not just a quaint side show but *everything*—the true source of physical law, including perhaps the most fundamental laws we know. (Laughlin (2005), p. 208)

In the next section I turn to methodological implications and fundamental laws. But here we also see the focus of emergentists on quantitative accounts of the behaviors of parts. Amongst the lessons learned from such empirical findings by emergentists like Laughlin are, first, that parts can behave differently in wholes, so they really do have differential behaviors/powers; and, second, that parts behave in these new ways because the whole (and/or its activities or properties) determines that these parts have differential powers and the differential behaviors that result.

Here is how Walter Freeman frames the resulting Mutualist picture in the cases in the neurosciences he focuses upon involving neurons in populations. Freeman tells us:

> An elementary example is the self-organization of a neural population by its component neurons. The neuropil in each area of cortex contains millions of neurons interacting by synaptic transmission. The density of action is low, diffuse and widespread. Under the impact of sensory stimulation, by the release from other parts of the brain of neuromodulatory chemicals… all the neurons come together and form a mesoscopic pattern of activity. This pattern simultaneously constrains the activities of the neurons that support it. The microscopic activity flows in one direction, upward in the hierarchy, and simultaneously the macroscopic activity flows in the other direction, downward. (Freeman (2000), pp. 131–132)

Here we have the core idea of Mutualism applied to a concrete case. We have a whole (and its activities and properties) in a population of neurons upwardly composed by neurons (and their activities and properties). But at the same time this whole (and its activities and properties) also downwardly determines (and “constrains”) these component neurons (and/or their activities and properties) which consequently have differential behaviors and powers.[11]

We should mark that the downward determinative relation from whole to parts is not a compositional relation, since parts (and their activities and properties) together usually fill the causal roles of a whole (and its activities and properties). But a whole (and its activities and properties) cannot fill the causal role of its parts (and their activities and properties), nor hence compose them. This synchronic determinative relation is also not a causal one, since it again has features that causal relations lack such as being synchronous relations, holding between entities that are in some sense the same and involving synchronous changes in their relata. So we have a novel, downward, synchronic determinative relation, from whole to parts (and/or their activities and properties), that I have elsewhere dubbed a “machretic” relation.

[11] Strictly speaking, it is most plausibly an “emergent” activity or property of a whole that downwardly (machretically) determines that a realizing property of some part contributes a differential power and hence has a differential behavior/activity. However, for ease of exposition I have throughout the paper talked about wholes downwardly determining parts. The reader should take me to mean this more nuanced situation involving an activity or property of a whole when talking of such whole-to-part determination.

It is worth noting that under Mutualism wholes have at least two kinds of causal relations. At their own levels, wholes productively act "horizontally" on other wholes in *thick* causal relations of activity—thus a muscle acts upon sinews and bones when contracting. But, in addition, when we have such machretic relations at a time, where a whole (or more precisely one of its properties or activities) determines some property of a part contributes a differential power, then over time we will have *thin* causal relations (such as relations of manipulability) between the whole (and/or its relevant activity or property) and the differential behavior of the part that results from this power at some later time.[12] Removing the activity or property of the whole will remove the differential power of the part and hence the differential behavior. So machresis between whole and parts (or their activities and properties) at a time leads to thin downward causal relations over time between the whole (or its activities and properties) and differential behaviors of parts of this whole. Machresis thus always results in a species of thin downward causation and many scientific emergentist frame their views around such "downward causation".[13]

At this point, many philosophers object that this kind of situation is incoherent for various reasons.[14] Most commonly, philosophers and scientists seek to use the Argument from Composition, or related arguments about mental causation (Kim, 1993b), to conclude that we should never accept a whole is both composed and causally efficacious—and hence should not accept anything like Mutualism under which wholes are determinative in various ways, including causally. However, once we appreciate Mutualism, we can see that such arguments are plausibly invalid when they proceed from the assumption of compositional relations alone, rather than also assuming stronger claims like the Completeness of Physics.

Recall that the crucial sub-conclusion of the Argument from Composition is that in cases of comprehensive compositional explanation using parts alone accounts for, or explains, everything at the higher and lower level. However, when we have differential behaviors and powers of parts, and Mutualism is true, although all wholes (and their activities or properties) are the subjects of successful compositional explanations, we still *cannot* account for all the behaviors and powers of individuals solely using parts or their activities/properties. For the differential behaviors and powers of parts have not been explained. In this type of case, the premise that we have compositional explanations is true, but the sub-conclusion that we can explain everything with parts alone is false—so we can see that the Argument from Composition is invalid and similar points hold for related forms of Kim's argument about mental causation.

Scientific reductionists, and other proponents of reasoning like the Argument from Composition, have locked themselves into the assumptions, first, that the parts in wholes never in principle need explanation beyond that offered in simpler systems. And, second, that we only ever have upward determination. But these researchers thus

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[12] Thick causal relations are usually relations of activity. In contrast, thin causal relations are captured by manipulability or difference-making accounts that require not such relation of activity between their relata.

[13] For more discussion, see Gillett (2020) and (2016a), Chap. 7.

[14] Gillett (2016a), Chap. 7, reviews a range of such concerns and offers rebuttals.

overlook options that scientific emergentists, like Prigogine, Laughlin, and others, claim empirical findings, about Challenging Compositional Cases, bring to the fore—parts can have differential behaviors/powers and the latter can be machretically determined downwardly by a whole or its activities/properties.

We can therefore see that a mistaken theoretical reason, in an alluring but invalid argument, has wrongly been used to dismiss natural phenomena that did not fit the scientific reductionist's reasoning and hence guiding picture. But, as Laughlin puts it in our opening passage, "The great power of science is its ability, through brutal objectivity, to reveal to us truth we did not anticipate".[15] And that power of science has produced empirical findings that, scientific emergentists argue, reveal the flawed assumptions, and invalid reasoning, used to justify the standard versions of scientific reductionism.

5 A New Guiding Picture of Nature and its Implications

Scientific emergentism, through its Mutualist view, offers us a guiding picture of nature, but is this picture really different from that of "reductionism"? In answering this question we need to be careful of the ambiguity we have now revealed over what we mean by "reductionism", since we actually confront two questions: How is the guiding picture of scientific emergentism different from that of *everyday* reductionism? And in what ways does it diverge from that of *scientific* reductionism? I take these questions in turn and show we get starkly different answers.

With regard to everyday reductionism, and the search for compositional explanations, we actually find overlap. As Laughlin explains about his main emergentist conclusion:

> One might subtitle this thesis the end of reductionism (the belief that things will necessarily be clarified when they are divided into smaller and smaller component parts), but that would not be quite accurate. All physicists are reductionists at heart, myself included. I do not wish to impugn reductionism so much as to establish its proper place in the grand scheme of things. (Laughlin (2005), p. xv)

Once we understand Mutualism, then we can see why Laughlin thinks scientific emergentists are clarifying the proper place of the search for compositional models and explanations, rather than abandoning that approach.

The guiding picture of scientific emergentism *supplements* that of everyday reductionism. Scientific emergentists take everything to be composed and they continue to accept that it is productive to search for compositional models and explanations. For all Mutualist cases are examples of individuals, and their activities and properties, that are composed by parts, and their activities and properties. But under Mutualism we have *added* the possibility of downward determinative relations of machresis at a time, and consequent thin downward causal relations over time, *alongside* the upward compositional relations endorsed by everyday reductionism.

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[15] Laughlin (2005), p. xvi.

As I detail in the next section, these additions provide new resources under scientific emergentism to engage the cases where everyday reductionism hits a wall. However, let us now consider the differences with the guiding picture of scientific reductionism and its methodological advice. One place to highlight such differences concerns the fundamental laws and fundamental research.

As I outlined above, the nature of everyday reductionism, and compositional explanations, make parsimony arguments alluring. As the scientific emergentist Philip Anderson cautions us, once we accept everyday reductionism:

> It seems inevitable… [to accept] what appears at first sight to be an obvious corollary of [everyday] reductionism: that if everything obeys the same fundamental laws, then the only scientists who are studying anything really fundamental are those working on those laws… This point of view… it is the main purpose of this article to oppose. (Anderson, 1972, p. 393)

Here we see one of the key contentions of scientific reductionism that its stronger conclusions follow from everyday reductionism. But why does Anderson claim this conclusion is mistaken? Once again focusing on our more detailed empirical findings about the behavior of the parts in wholes, Anderson claims that:

> The behavior of large and complex aggregations of elementary particles, it turns out, is not to be understood in terms of a simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other. (Anderson, 1972, p. 393)

As we have seen, scientific emergentists contend that the behaviors of parts in wholes are not those these parts would have if the accounts, and laws, in simpler systems were exhaustive. Instead, parts are claimed by scientific emergentists to have differential behaviors determined by wholes (and/or their activities or properties) and hence covered by new fundamental laws applying within certain wholes. Laughlin tells us:

> From the reductionist standpoint, physical law is the motivating impulse of the universe. It does not come from anywhere and implies everything. From the emergentist perspective, physical law is a rule of collective behavior, it is a consequence of more primitive rules of behavior underneath (although it need not have been), and it gives one predictive power over a limited range of circumstances. Outside this range, it become irrelevant, supplanted by other rules that are either its children or its parent in the hierarchy of descent. (Laughlin (2005), p. 80)

Under Mutualism, we thus have a complex array of fundamental laws covering parts and their behaviors: some hold in simpler systems but other fundemental "organizational" laws only hold of these parts in certain wholes.

Such laws deserve much more discussion which I have pursued elsewhere (Gillett (2016a), Chap. 7). But for our purposes here we begin to see a stark methodological difference that results from the guiding pictures of scientific reductionism and emergentism. Under scientific reductionism, fundamental physics has a monopoly on fundamental phenomena, research and laws. But under the guiding picture of scientific emergentism, as Anderson emphasizes, *many* sciences, studying nature at *many* levels, can be investigating fundamental nature phenomena, exploring the "frontiers" of fundamental research and discovering fundamental laws (Laughlin (2005), pp. 5–8).[16]

6 New Models and New Explanations: Resources for Challenging Compositional Cases and Beyond

Finally, let us return to local concerns and concrete scientific examples. We can now appreciate how the new guiding picture of nature of scientific emergentism supplies novel resources in such examples. As we saw with compositional explanations, we often give ontic explanations that explain natural phenomena by representing determinative relations in nature that result in the phenomena to be explained. To take another example, causal explanations represent various kinds of causal relation to provide ontic explanations. The foundational point is that such explanations work by representing ontological relations in nature. But Mutualism recognizes novel determination relations in nature in various kinds of machretic relation. Hence Mutualism allows a new class of models and explanations representing, and backed by, these new relations.

For example, under Mutualism one can now offer models and explanations that posit either machretic relations from wholes (or their activities or properties) to parts (or their activities or properties) at a time, or that posit thin, downward causal relations between these entities over time that result from such machretic relations. We could use the terms "whole-to-part", "machretic" or "downward causal" models/explanations for these various scientific products, but let me here simply dub them all "Mutualist" models/explanations given their connection to Mutualism.

Such Mutualist models/explanations may take all manner of forms. For instance, one can posit models representing machretic relations or thin downward causal relations. And one can construct models which variously take such relations to have individuals, activities or properties as relata. So these models can vary in their posited ontology. Furthermore, one can use different representational formats for such models. Thus one can use non-linear dynamics to articulate such models/explanations, but one can also use new network models/explanations to do the same. And a host of other mathematical and representational formats can be used to the same end.[17]

It is important to note that all of these representational formats can be used to give other models/explanations than such Mutualist ones. What is crucial is the intended, and/or the most plausible, interpretations of such successful applications of non-linear dynamics, network models, and so on. In each case, and for each application in this example, it is a substantive task to show either that researchers intend their

[16] For a more detailed discussion of the new methodologies under scientific emergentism se Mitchell (2009).

[17] See Juarrero (1999) for discussion of some of these Mutualist models and their features.

model to be a Mutualist one, or to show that some successful model is most plausibly interpreted as representing Mutualist relations.

It is therefore very much an ongoing question where Mutualist models/explanation may be productively applied and also an open issue where recent successful scientific work supports the existence of Mutualist scenarios in nature. My goal here is not to explore or resolve such questions, though elsewhere I have tried to begin to clarify what is involved in addressing them.[18] Instead, my focus has been on illuminating the Mutualist revolution and how the new guiding picture of scientific emergentism offers resources to researchers at the cutting-edge of science. And we have now found this to be the case. To properly see this, let us briefly return to Challenging Compositional Cases.

The key point is that we can *supplement* causal and compositional models/explanations in Challenging Compositional Cases with Mutualist models/explanations in the attempt to account for the behaviors of parts in the relevant complex wholes. Thus we can offer models positing machretic relations between a whole (or its activities or properties) and differential behaviors/activities or powers of a part or its property. Similarly, we can offer associated models positing a variety of thin, downward causal relations from wholes, or their properties and activities, to differential behaviors of parts. Machretic, and/or downward causal, relations can thus offer new models and explanations to understand such differential behaviors of parts. Note that such Mutualist models/explanations will be integrated with causal and compositional models/explanations, so these Mutualist models/explanations supplement, rather than supplant, the resources provided by everyday reductionism and other existing approaches.

Mutualist models thus offer researchers new resources in cases where we saw everyday reductionism has hit a wall. As Laughlin emphasized in an earlier passage, scientific emergentism is thus both broadening our methodological tool-kit and also putting compositional models/explanations in their proper place as one amongst a number of useful kinds of ontic model/explanation.

7 Conclusion

It bears emphasis that scientific research on Challenging Compositional Cases is very much ongoing. It is an open question whether Mutualist models and explanations, for example, provide the best accounts of electrons in superconductors, or proteins in cells, or a host of other cases. And it is a difficult connected, and ongoing, issue of whether successful approaches in such cases, for example using non-linear dynamics, network models, and so on, are best interpreted as being examples of Mutualist models or not. Thus it remains to be established whether we really have differential behaviors or powers in Challenging Compositional Cases.

[18] See Gillett (2016a), Chaps. 8 and 9.

I should also note that scientific reductionists can rework their views *even if they accept parts have differential behaviors and powers*. Here I have discussed the standard, or what I term "simple", version of scientific reductionism. But elsewhere I have sketched how one can revise scientific reductionism in what I term a "conditioned" version that accepts parts have differential behaviors and powers, but takes such differential behaviors/powers of parts to be determined, and hence explained, solely by *other parts*.[19] The conditioned variant of scientific reductionism offers novel models and explanations that can also potentially be used to gain traction with Challenging Compositional Cases. Consequently, both simple and conditioned scientific reductionist approaches need to be engaged by scientific emergentists, as relevant rivals, when they defend their treatments of various concrete cases.[20]

However, my focus here has not been on the new options for scientific reductionism. My goal has been to illuminate the exciting revolution that scientific emergentists have been working to achieve in so many areas of the sciences. Scientific emergentism, through its novel Mutualist guiding picture of nature, broaches new whole-to-part relations in the natural world, whether machretic relations at a time or thin downward causal relations over time. Consequently, the scientific emergentist's guiding picture of nature offers fresh resources for researchers in models and explanations backed by these novel relations. One can only be excited to see how, over coming decades, these new Mutualist models and explanations perform for us at the frontiers of science.

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[19] See Gillett (2016a), Chaps. 8 and 9, for an exploration of conditioned scientific reductionism and its contrasts, and overlap, with the standard version of this position.

[20] See Gillet (2016a), Chaps. 9 and 10, for my more detailed take on what this might involve.

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