Introduction

I think a good case can be made that science has now moved from an Age of Reductionism to an Age of Emergence, a time when the search for ultimate causes of things shifts from the behavior of parts to the behavior of the collective.

– Robert Laughlin[1]

When you are criticizing the philosophy of an epoch, do not chiefly direct your attention to those intellectual positions which its exponents feel it necessary to defend. There will be some fundamental assumptions which … the epoch unconsciously presuppose[s]. Such assumptions appear so obvious that people do not know what they are assuming … With these assumptions a certain limited number of types of philosophic system are possible, this group constitutes the philosophy of the epoch.

– Alfred North Whitehead[2]

As we start the new century, we find ourselves in the midst of a new cycle of scientific debates over "reduction" and "emergence" or what we may colorfully term, following Robert Laughlin the Nobel Prize-winning physicist and scientific emergentist, a new "Battle of the Ages." For defenders of the Age of Reductionism, like the other Nobel Prize-winning physicist Steven Weinberg, biologists like Francis Crick or E. O. Wilson, and many others, are not giving up without a fight. We find clashes between the two sides across bitter fights in physics over the supercollider or high-energy superconductors, biological debates over cells and their molecular components, disputes over neurons and neuronal populations, and many other concrete cases at various levels of the sciences.[3]

[1] Laughlin (2005), p. 208.
[2] Whitehead (1925), p. 71.
[3] See Scott (2007) for a more comprehensive survey of such examples.

It is hard to come by clear formulations of the opposing hypotheses pressed by scientific reductionists and emergentists about such examples, but each side does supply pithy slogans to publicize their claims. Thus scientific reductionists continue to press increasingly sophisticated views under the banner that "Wholes are nothing but their parts." On the other side, scientific emergentists of this generation, like Laughlin or the other condensed matter physicist Philip Anderson, chemists such as Ilya Prigogine, neuroscientists like Walter Freeman, and many in systems biology or the sciences of complexity, still defend ontological positions claiming that "Wholes are more than the sum of their parts," but the new wave of emergentists now make the latter claim alongside views that I contend can be sloganized as "Parts behave differently in wholes."[4]

Superficially, one might therefore think that very little has changed in the sciences. At the beginning of the *last* century, one of the great scientific disputes also raged between reductionists and emergentists of various kinds.[5] However, closer inspection reveals important differences with these older debates whose central question was whether all natural phenomena are *composed* and, in particular, the chemical and biological entities whose composed status had, at that point, remained inscrutable for decades. Putting the issues in a different way, the earlier battles focused on whether all levels of nature, including chemical or biological phenomena, were amenable to what I shall term "compositional explanation" – that is, to explanations of higher-level entities built around lower-level entities taken to *compose* them. Famously, however, during the course of the twentieth century the rise of quantum mechanics and molecular biology finally provided compositional explanations in chemical and biological cases. And such headline-making advances occurred against the backdrop of continuing waves of compositional explanation in the full range of other sciences. The earlier debates were consequently settled in the sciences, since these explanations provided *qualitative* accounts of the components of the entities found at many levels of nature, including chemical and biological phenomena.

[4] The second slogan, as I show in Chapters 6 and 7, expresses a central claim of contemporary scientific emergentists once we dig into their ontological commitments.

[5] For example, see Haraway (1976) for a survey of these earlier battles in biology.

But scientific innovation never ceases and amongst recent advances, as Laughlin notes, is our improved understanding of the components of complex aggregations, or "collectives" to use Laughlin's term, from high-energy superconductors, to eukaryotic cells, and on to slime mold, neural populations, or eusocial insect colonies. Often using new techniques, for the first time we now also often have *quantitative* accounts of the components found in such complex collectives. And these discoveries apparently fuel our new cycle of debates. Thus contemporary scientific reductionists and emergentists each apparently endorse the ubiquity of compositional explanation and their disputes no longer concern the *existence* of composition at all levels in nature, but instead focus upon opposing accounts of its *character* and *implications*. The two sides thus clash over an array of what Whitehead would class as diverging *epochal* ontological commitments implicitly assumed by either side in contrasting views of the very nature of composition (i.e. "parts" and "wholes"), the form of the aggregation that always accompanies such composition, the varieties of determination we find in the universe, and the character of the fundamental laws, amongst a variety of other issues.[6]

These exciting debates focus on Big Questions of interest to anyone concerned with what the sciences tell us about the structure of the universe or the best ways for understanding it. Unsurprisingly, the scientific disputes have consequently played out not just across academic journals and monographs in the sciences, but also across a dizzying array of best-selling books, newspaper and magazine articles, and even congressional hearings.[7] However, in contrast to this popular engagement, philosophers have shown comparatively little interest in such scientific discussions.

It is striking that philosophers, at least in any numbers, have not engaged the scientific debates, though there have been notable

[6] On one plausible story, Anderson (1972) arguably fired the first salvo in the present cycle of contemporary debates and four decades later the scientific disputes only burn more brightly.

[7] The congressional testimony was focused on the funding of the so-called "supercollider" that was taken to be central to the scientific reductionist program. For a matched pair of books setting out the two sides of the ensuing debates, see Weinberg (1992), written as a defense of the supercollider, and Laughlin (2005), which provides the contrasting emergentist perspective. For just a few of the other books on these debates, again from both sides, see Holland (1999), Lewin (1992), and Wilson (1998).

exceptions.[8] And some philosophers have even taken the time to dismiss scientific discussions of reduction and emergence as mere empty rhetoric used to support funding grabs.[9] This situation is not so surprising, since philosophers have erected their own proprietary views of the nature of scientific composition, reduction, and emergence diverging from the accounts apparently used in the sciences. Applying their different theoretical frameworks, the reigning view in mainstream philosophy is consequently that reductionism is basically a *dead*, and perhaps even somewhat *distasteful*, position. And many (most?) philosophers dismiss discussions of emergence as, at best, *kooky* and, at worst, *incoherent* (to use far more polite terms than are usual in such dismissals).

Scientists in recent debates are well aware of these dislocations with philosophical discussions. *Both* scientific reductionists *and* emergentists take a jaundiced view of philosophical frameworks that do not comfortably fit their views or what they see as the deeper issues. Thus one finds Weinberg explicitly spurning philosophical models of reduction, repeatedly pressing the different nature of his scientific reductionist position, and penning a chapter entitled "Against Philosophy."[10] And the emergentist biologist Ernst Mayr counsels avoiding the received philosophical frameworks for reduction and emergence, since he concludes that such frameworks distort the issues in damaging ways.[11]

It is obviously troubling to find theoretical differences between philosophical and scientific debates on such important topics. And it leaves us with a pressing question: Are philosophical or scientific

[8] I locate the work of these writers in the frameworks of coming chapters. For example, Jaegwon Kim, and writers such as Alexander Rosenberg, John Heil, Andrew Melnyk, and Barry Loewer, press ontological accounts of reductionism with affinities to scientific reductionism. And other writers such as John Bickle and Kenneth Schaffner have directly engaged the kinds of reduction espoused by scientists in specific scientific cases. With regard to emergence, Mark Bedau, John Dupré, Robin Hendry, Alicia Juarrero, Sandra Mitchell, Robert Richardson, and Achim Stephan, amongst others, have all begun to engage the claims of various species of scientific emergentist.

[9] The suggestion that philosophers of science should not co-facilitate such rhetorically based funding grabs, and hence should abandon the terms "reduction" and "emergence," was forcefully pressed by the philosopher of physics John Norton at the 2009 Paris–Pittsburgh Conference on Reduction and Emergence held at the Pittsburgh HPS Department.

[10] Weinberg (1992), Chapter 7. See his (2001) for similar sentiments.

[11] See Mayr (2002).

approaches to reduction and emergence, as well as connected foundational issues such as the nature of scientific composition, more likely to be closer to the truth about the deeper issues and live positions of our times? One of my main negative conclusions in this book is that the scientists are right to be wary, for I show at length that the received philosophical wisdom has gotten things dead wrong about the nature of scientific composition, the varieties and implications of reduction and emergence, the viable positions, and the deeper issues between them. And I show that even those philosophical pioneers who have hit on one of the live views, embracing positions akin to either scientific reductionism or emergentism, have still overlooked the strongest opposing views, missed the deeper issues, and formed flawed conclusions about what our empirical evidence has shown. I consequently also establish that philosophers on both sides of the debates have misstepped in their arguments and assessments of our empirical evidence based upon them.

Perhaps more importantly, on the positive side, I highlight how reconnecting with, and following, the scientific debates allows us to correct these deficiencies and finally appreciate the very different intellectual landscape in which our recent empirical advances have left us. However, I also illuminate the ways in which the scientific debates themselves need better theoretical frameworks to move beyond their present stalemate by articulating their arguments and positions in order to properly appreciate the new debates and move them forward. I subsequently show that scientific emergentists and reductionists have also overlooked the strongest opposing views, and the key issues with these rivals, thus also leading these scientific researchers to flawed conclusions about what our empirical evidence has shown so far.

Some Big Claims about Still Bigger Debates

Much of the work of later chapters is devoted to providing detailed arguments to support these conclusions, but even at the outset I suggest we have some compelling reasons at this point to favor the sciences as the place to look for insight in order to move the debates over reduction and emergence forward.

First, compositional explanations, and connected empirical findings, plausibly provide our core empirical evidence about the structure of

nature both locally and globally. Scientific reductionism and emergentism are each focused directly on such explanations, so engaging these views provides a way to reconnect with our core empirical evidence and more carefully assess where it leaves us, thus refreshing and reorienting our discussions. Although philosophical debates have often focused on "global" positions or theses, about the whole of nature, my primary focus throughout the book therefore follows the sciences in being "local" and trained on specific examples of compositional explanation in the sciences and their implications.

Second, the concepts of composition used in the sciences, the notions of "parts" and "wholes" that underpin both scientific reductionism and emergentism, are used in our awesomely successful compositional explanations. Such explanations are basically the most successful explanatory applications of compositional notions to entities in nature. In contrast, putting it politely, it is far harder to see what the explanatory successes are for the philosophical frameworks recently used to understand composition in nature. To the degree to which we take explanatory success to be a marker of truth, we should thus favor scientific notions of composition, rather than philosophical frameworks, as reflecting the structure of nature. And we therefore have clear reasons to take the scientific positions directly focused upon the implications of such concepts to be more likely to engage the deeper issues.

Third, I have already marked how debates over reduction and emergence have gone through a continuing evolution because they have an important empirical component. And empirical evidence can plausibly be expected to play a key role in transforming, or having transformed, contemporary debates. Given their closer contact with scientific innovations, scientists plausibly react more swiftly to empirical advances than philosophers. So we have another reason to favor engaging the scientific positions because scientific debates often more swiftly reflect important empirical advances than philosophical discussions. I detail in later chapters how this is just the situation that has come to pass in the distinct sets of debates over reduction and emergence in science and philosophy.

Fourth, and finally, by carefully following the scientific debates, and focusing on specific examples of compositional explanation, we can get a better, clearer grip on our present epistemic situation to discern which positions are alive or dead and why. Consequently, we have the

chance to discern to what degree the debates are empirically resolvable and what types of evidence are relevant to the key disputes. Building on such a platform, we can therefore refresh and reorient the debates by illuminating what has really been established so far from empirical evidence in various cases, or even globally, and hence also clarify the future work that can address the open questions.

My starting hypothesis is therefore that scientific concepts and positions come closer to the deeper issues, and live positions, of our day than those of philosophy. And, as we begin to explore the claims of scientific reductionists and emergentists, it is important to be neutral between the various sciences, since one of the hotly contested questions between the two sides in the sciences concerns the relative status of various scientific disciplines. As a working assumption, I thus also endorse what I term "Inclusivism" in the position that we need to consider evidence from a *range* of sciences, and not just fundamental physics, in addressing issues over reduction and emergence.[12] Overall, in contrast to much recent philosophy, *I therefore side with the sciences, but I do not take sides between the higher and lower sciences except where I identify good reasons*.[13]

Though following the sciences, I also show that many of the central notions, theses, arguments, and commitments of the battling positions in the sciences have remained largely unarticulated, just as Whitehead would predict, since they are, or are based upon, unarticulated epochal ontological assumptions implicitly assumed by the protagonists on either side of the debates. Given the unfortunate state of the theoretical frameworks in the scientific discussions, my primary goal is therefore to provide more adequate, positive theoretical accounts of

[12] The alternative position is what I dub "Exclusivism," which takes fundamental physics to be the only science whose evidence is required to resolve debates over reduction and emergence or the structure of nature. Consider, for example, the explicit, Exclusivist position in Ladyman and Ross (2007). Many other philosophers have often recently fallen into Exclusivist positions, but I show that scientific reductionism, when properly understood, endorses Inclusivism.

[13] My stance thus deliberately mirrors a maxim of David Lewis, but then tweaks the resulting claim to avoid either the obvious reductionist or Exclusivist bias it contains. Famously, Lewis suggested: "Materialist metaphysicians want to side with physics, but not to take sides within physics" (Lewis (1983), pp. 37–8). But this makes the blatantly reductionist or Exclusivist assumption that there is only one science of interest, physics, in debates over reduction and emergence.

the scientific notions of composition deployed in compositional explanations and then for the positions of scientific reductionists and emergentists that build upon them.

As a way to move the scientific discussions forward, my theoretical focus obviously contrasts with a "More Data" strategy that simply seeks to pile on more, and more, empirical findings to resolve the scientific disputes. However, the More Data approach now looks ineffective. As we shall see, we do not lack for data and both sides have declared victory because they each claim our empirical evidence has settled the issues – but in favor of opposing views! The scientific debates have thus bogged down into a de facto stalemate. In this situation, the old scientific saw that "Theory without data is useless, data without theory is blind" appears to offer sound guidance. And I therefore contend that our most pressing need is presently for better theory to understand the scientific positions and finally clarify the empirical evidence relevant to confirming, or disconfirming, their opposing claims.

Given the shared focus of scientific reductionists and emergentists on the notions of composition deployed in compositional explanations, i.e. the "parts" and "wholes" in their slogans, I begin by constructing a theoretical framework for these foundational phenomena. My approach, in its first step, is to *start* with the scientific explanations and their notions, describe the features of these concepts, and *then*, in its second step, to construct a theoretical framework that captures the highlighted features of these scientific notions of composition. My methodology thus contrasts with recent philosophical approaches that pay little detailed attention to the nature of scientific notions of composition and simply seek to shoehorn such concepts into pre-existing philosophical machinery developed for other purposes. Using real scientific examples, I confirm that existing philosophical frameworks provide inadequate accounts of scientific composition because they fail to accommodate key features of such notions.

Taking my better account of "parts" and "wholes" in the sciences as a platform, I then repeat this procedure for scientific reductionism and emergentism in turn. Once more, I start with each scientific position to describe its commitments and arguments in the first step, and then in the second step construct a theoretical framework for the view, rather than simply seeking to jam the scientific position into pre-existing philosophical accounts of either reduction or emergence.

Again I establish that this approach is warranted. I show that scientific reductionists and emergentists both defend novel positions largely overlooked by philosophers, and that each of these views highlights significant flaws in the dominant philosophical accounts of reduction and emergence. Still more importantly, and contrary to the received wisdom in philosophy, I ultimately establish that the kinds of position articulated in the scientific debates exhaust the two kinds of live positions in contemporary debates, whether in science, philosophy, or more widely.

I therefore pursue this *three-step methodology* throughout the book. First, I pursue a descriptive project of articulating the features of a scientific concept or position. Then, second, using my descriptive account, I construct a theoretical framework for the concept or position that allows me to assess the arguments built upon the concept or position. But my work is thus not merely descriptive, although its initial phase does focus on articulating and theoretically reconstructing scientific concepts and positions. For, third, I then also prosecute the *prescriptive* project of assessing both philosophical, but also scientific, positions and arguments about scientific composition, reduction, and emergence.[14]

For instance, using my better theoretical frameworks, I outline why the most widely endorsed views in philosophy and the sciences are not amongst the viable positions about the structure of cases of compositional explanation. And I illuminate the false dichotomies philosophers have endorsed about both reduction and emergence. However, I also detail a number of places where both scientific reductionists and emergentists have made bad arguments. For example, I detail how the most common argument offered by scientific reductionists for their claim that "Wholes are nothing but their parts" is actually *invalid*. And, contrary to the claims of scientific emergentists, I outline why the existence of multiple realization, feedback loops, the indispensability of higher sciences, and/or the necessity of using non-linear dynamics or explanation by simulation do *not* alone provide good arguments against scientific reductionism once it is properly understood.

Appreciating the flawed arguments recently offered in the sciences, and in philosophy, I show that both sides in scientific debates, although each hitting on one of the live positions, have plausibly failed

[14] For a more detailed discussion of this methodology see Gillett (2016).

to appreciate the strongest *opposing* views. And I show that similar problems affect even those philosophers pursuing pioneering work on the scientific views. Given the comparative nature of scientific theory appraisal, where a theory is assessed by comparison to the strongest relevant rivals, I consequently show that extant defenses using empirical evidence from both scientific reductionists and emergentists, as well as their allies in philosophy, are presently all plausibly unsuccessful. My theoretical work thus illuminates how our Battle of the Ages is very much an *ongoing* one and rather different than even participants in the scientific debates, let alone philosophers, have supposed.

My final conclusion is that Laughlin is correct that we have indeed entered a very different era focused upon collective phenomena and their components. But I show how the protagonists on all sides of the debate, in philosophy and the sciences, including emergentists like Laughlin, need to make important adjustments to this new era. I highlight how we need to recalibrate philosophical discussions and replace existing philosophical accounts with more adequate theoretical frameworks for scientific composition, reduction, and emergence that highlight the very different nature of the live positions and underlying issues of our new debates. But I also move the scientific discussions forward by providing abstract theoretical frameworks that clarify the key scientific positions and their epochal claims, allow us to evaluate which of their arguments are good and bad, illuminate their differences about the structure of concrete scientific cases – and hence see how to empirically break the deadlock over such examples.

The Dislocation between Philosophy and the Sciences – and a Way Forward

Coming chapters range over often highly theoretical debates, in science and philosophy, and challenge a swathe of received philosophical wisdom. So to guide the reader I now want to provide overviews of the contents of the book's four parts in turn. Clearing space for later work is my focus in Part I, "Groundwork," where I provide brief overviews of the state of scientific and philosophical debates, diagnose the disconnect between them, and then construct a theoretical framework for scientific composition that helps to bridge the gap.

Chapter 1 provides surveys of scientific reductionism and emergentism, outlining how each position is pursuing what I term the