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PHILIP CLAYTON

14 On the plurality of complexity-producing mechanisms

When you stir your rice pudding, Septimus, the spoonful of jam spreads itself round making red trails like the picture of a meteor in my astronomical atlas. But if you stir backwards, the jam will not come together again. Indeed, the pudding does not notice and continues to turn pink just as before. Do you think this is odd?

If knowledge isn't self-knowledge it isn't doing much, mate. Is the Universe expanding? Is it contracting? Is it standing on one leg and singing 'When Father Painted the Parlour'? Leave me out. I can expand my Universe without you. 'She walks into beauty, like the night of cloudless climes and starry skies, and all that's best of dark and bright meet in her aspect and her eyes.'

Tom Stoppard, *Arcadia*

It might seem obvious that the Universe becomes more complex over time. After all, isn't a gas cloud consisting only of hydrogen and helium a few seconds after the Big Bang simpler than a cloud of hydrogen, helium, carbon, silicon, and oxygen two billion years later? Aren't the dynamics of a system at the level of particle physics simpler than the dynamics of a group of interacting cells?

As intuitive as these proposals are, we don't currently possess an adequate quantitative measure of the increase or decrease in complexity either across cosmic evolution or across scientific disciplines. In the past, many theorists presupposed that the gap between actual entropy and maximum entropy is not permanent, that heat death will win in the end. These theorists were eager to link complexity in a quantitative way to this "entropy gap", so that the two would rise and fall together. Others now

Complexity and the Arrow of Time, ed. Charles H. Lineweaver, Paul C. W. Davies and Michael Ruse. Published by Cambridge University Press.

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argue that, in an expanding Universe, the maximum possible entropy will increase more quickly than actual entropy, casting the "heat death" hypothesis into question. A variety of contentious topics in physics – the thermodynamics of black holes, quantum effects at macroscopic levels, and the energy density of the vacuum, among others – raise skepticism about over-quick applications of thermodynamics to cosmology. These same factors should make us cautious about construing complexity as "nothing but" the entropy gap. As a field of study, it is much richer than that.

"Complexity" is therefore not (yet?) the Grand Unified Theory of cosmic evolution, a single scientific framework adequate to describe all physical processes.[1] Complexity does not increase in a simple, straight-line fashion, any more than entropy does. Nor are all emergent properties more complex than the lower-level systems that produced them. We recognize that simpler systems combine to produce new, more complex systems. But we don't currently have sufficiently general language to describe and quantify this process. This is one of the great scientific puzzles of our day.

Despite these limitations, many theorists are tempted to take the universalizing ambitions of classical physics and to apply them to complexity theory, effectively making complexity a Theory of Everything. I share these theorists' fascination with complex systems, but for the opposite reason: the diversity rather than the unity of complex systems. Certain tempting generalizations notwithstanding, the sciences of complexity in fact study a vast variety of *distinct complexity-increasing mechanisms and systems*. On more skeptical days, I suspect that these various sciences have little more in common than the fact that they describe phenomena that we like to call "complex".

Mine is not a skepticism about the new foci of study. The topics covered in this volume, and in a host of recent conferences, are theoretically fruitful. Modeling the different types of complex systems and understanding how complex adaptive systems are able to function so successfully in different contexts is an important growth area in science. Interesting results follow from studying locally complex systems, even if they do not generalize across all of cosmic history. The detailed mathematical work is rightly creating dissatisfaction with long-accepted

[1] It's always perilous to name specific examples. Still, one does discern that some of the chapters in this volume tend more strongly in this direction. The chapters by Davies, Lineweaver, and Chaisson come to mind in this regard.

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accounts of information and emergent properties – just to name two of the most important implications – and is giving rise to a variety of new proposals in specific sciences. Some of these are beginning to bear fruit, and others have the potential to lead to important scientific advances in the future. Perhaps some of the chapters in this volume fall into this category.

Instead, my skepticism is raised by a particular approach to complexity, which we might call the Unity Approach. The Unity Approach takes two forms. Sometimes it appears as the attempt to construct *a single science of complexity*, which is supposed to look different from any science we've ever done before, to provide a new theoretical basis to many of the specific sciences, and to unify them as fully as the "unity of science" movement in the mid-twentieth century ever dreamed. At other times this approach manifests when a scientist assumes that his particular science is adequate to explain *all* complex systems.

We should resist the Unity Approach to complexity, I suggest, not just because the evidence does not warrant its claims – though that's a good reason – *but because it obscures a deeper insight that complexity theories offer into the way that cosmic evolution works*. The goal of this chapter is to try to put words on that insight. My starting point lies in current work in complex adaptive systems theory, though I do not pause to summarize that work here. Note, however, that thinking about common features across the various complexity proposals in the literature today means working at a meta-scientific level, since no single science currently exists that encompasses these proposals. To address this particular "big question" thus requires one to draw on one's philosophical competencies – even when the goal of the exercise is, in the end, to produce better science.

In order to resist slipping into the assumption that we currently possess a science of complexity (or a unified scientific account of it), I will use the locution "a theory of complexity" throughout. When theories of complexity gesture toward common features allegedly manifested by all complex systems in the natural world, such theories are speculative, meta-scientific, and hence philosophical. This point bears repeating. In our current context, a "theory of complexity" may designate a model of complex dynamics or a theory about the nature, causes, and explanations of complexity production *in some specific empirical discipline*. If it does not do one of these two things, it is (at present) a speculative theory about analogies or similarities between theories of complexity in specific scientific domains.

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The "sciences of complexity," I suggest, have at present four tasks:

- to describe and model complex dynamics;
- to produce the highest quality accounts we can currently give of complexity-producing mechanisms for some specified empirical domain and (where appropriate) to explain their adaptive function;
- to police against claims to scientific status for theories about "complexity as such"; and
- to contribute, as interest allows, to more speculative reflection on analogies between the various uses of "complexity" in the specific sciences.

It could well be that taking the focus off developing a single "science of complexity" will actually produce quicker progress on these tasks.

Several assumptions underlie this argument. Firstly, talk of complexity in evolutionary biology works only if one does not construe the increase in complexity as the primary goal of biological systems. That is, complexity-producing mechanisms (CPMs) don't *replace* differential selection as the motor of evolution. At the genetic level, effectively random variations produce phenotypical differences; those differences that increase the proportion of a given genome within a population constitute evolutionary success. Evolutionary success is, in the first place, always for the short term; it is relative to a specific fitness landscape. Because a given complex organism outperforms competitors in a given environment – say, *Tyrannosaurus* 70 MYA, or *Homo sapiens* today – does not mean that it, or complexity in general, is the telos of evolution as a whole. (We return to the question of macro-evolutionary patterns at the end.) It is not a fundamental assumption of evolutionary biology that more complex organisms are necessarily more fit for a given environment. (In fact, the more I watch Washington politics, the more ready I am to bet on the cockroaches.) And the fact that prokaryotes (the bacteria and the archaea) have continued to dominate their ecosystems for billions of years, despite the relative complexity of eukaryotic cells, shows that there is no inherent ability for the more complex cells to replace their simpler cousins. Remember that bacterial mutations are currently outperforming our best antibacterial agents in hospitals, human intelligence notwithstanding.

Secondly, I do not accept but will not here criticize four claims that one sometimes encounters: that the increase in complexity can never be quantified; that there is no net increase in complexity across evolutionary history; that we already possess a fully generalized (yet still

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empirical) theory of complexity; and that the dynamics of biological and cultural systems has been explained, or in principle could be explained, by a specific theory of the dynamics of physical or chemical systems.

Finally, the present chapter grows out of my recent work on complexity-producing mechanisms (CPMs) in evolutionary biology and culture, and in particular on the relationship between these two *kinds* of CPMs (Clayton, 2009). I turn to that relationship in the penultimate section but do not summarize all the arguments in the recent book. For example, for the argument to be complete, ecosystem dynamics and co-evolution in biology would have to be included, as would complex cultural and "network" dynamics such as the stock exchange and the growth of the internet. Ultimately, the complex worlds produced by the human brain – among them complexity theory itself – must surely be included among the data that a fully generalized complexity theory would have to address.

14.1 COMPARING COMPLEXITIES

I have contrasted theories of complexity in the context of specific scientific disciplines with more general debates about the nature of complexity. It doesn't take much reading in these general debates to recognize that they have a tendency to be constrained neither by data nor by well-established scientific theories. This should worry us. Hence the urgent need to develop a more disciplined approach to the current debates about complexity.

I suggest that we understand complexity, when used outside the context of a specific scientific discipline, as a theory about the relations between the more specific studies of complex systems. Theories *about theories* are called meta-level theories, or meta-theories for short. Complexity theory, understood as a meta-theory, is thus a multilevel and comparative concept.

I admit that this is a startling conclusion. After all, it's more common to talk about "the science of complexity". But we are actually only entitled to speak of the *sciences* of complexity – by which we must mean "the light shed on an (allegedly) general phenomenon by specific studies within specific disciplines". What then *is* complexity, if the analysis just given is accurate? Meta-theories are not directly scientific theories; they are not located within a specific field of science. Technically, I suppose, that makes them philosophical theories.

The very nature of many of the proposals currently being made about complexity should make clear that these proposals cannot be

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understood within the context of a single (existing) science. Or, put differently: if they are understood as proposals for a single new science of complexity, that science would function in a manner very similar to how Newtonian physics was supposed to function as a foundation for all science whatsoever. But a large variety of problems still have to be solved before we reach the point where such a "unified science" can be formulated.

My proposal for a meta-level theory of complexity is based on this fact. I suggest *that complexity emerges from a variety of complexity-producing mechanisms; that different mechanisms produce distinctive dynamics, different patterns of evolution over time; and that complexity may turn out, even ultimately, to be a meta-level phenomenon*, *that is, not a single science but a pattern, a tight or loose set of analogies, across a variety of specific empirical disciplines*.

I think there are good reasons for accepting this position. But the truth is, we don't yet know for sure. Thus the proposal is a prediction about how the study of complexity will develop over time. Since this prediction can't yet be tested, one should understand it as a sort of wager. I bet my dollar on this horse, and I think it's rational to do so. If you choose to bet on a different horse, we could have a good argument about who is more likely to be right in the long run. Still, don't forget that both of us are wagering. Until the race is run, no one knows who will be right.

Contrast complexity as a meta-level theory with, say, Newtonian physics. To have a universal Newtonian science would have meant that no meta-level scientific description of the Universe is more true than the Newtonian description. In fact, every possible scientific description of the Universe would have been subsumed under Newton's laws and become a special case of them. Newton's laws, together with an exhaustive description of the initial conditions (at some arbitrary point in time), would have sufficed to explain all natural phenomena past, present, and future. (Some twentieth-century variants added the requirement that one specify "bridge laws" between special sciences such as biology or psychology and the fundamental physical science. But at mid-century many physicists and philosophers took it as a matter of course that such bridge laws would soon be forthcoming (e.g., Nagel, 1961).) We now know that Newtonian physics is not a universal science in this sense; at velocities approaching c and in massive gravitational systems, relativistic effects unknown to Newton become significant. Similarly, I am betting that complexity will likewise not generalize across all systems. If this bet about the role of specific complexity-producing mechanisms is correct, it means that the dynamics of distinct systems will be irreducibly

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marked by the specific mechanisms or natural systems that produced them.

14.2 COMPLEXITY AND THE CULTURAL DIVIDE BETWEEN PHYSICS AND BIOLOGY

Discussions between physicists and biologists often stumble over a dichotomy that emerges at this point. The outcome is invariably a stalemate.

The one group claims that any generalizations we make – in this case, shared features that we recognize across the special sciences of complexity – will eventually evolve into mathematical models and then, ultimately, into the formulation of scientific laws. The other group (to which I belong) argues that the differences between complexity-producing mechanisms entail that no single set of laws will be adequate to the data. Consequently, we argue, generalizations about complex systems are meta-theories; the primary scientific work must lie at the level of specific complex systems – say in biology, genomics, proteomics, metabolomics; or cells, organs, organisms, ecosystems. When the level of culture is added, and even more when the meaning of specific cultural artifacts is being debated (as, for example, in the humanities), generalizations about complexity begin to include irreducibly philosophical concepts. By this point their status as philosophical theories is unmistakable.

It's not difficult to spell out the theoretical assumptions of this approach. Nature comes in levels (of organization). These levels are roughly (but only roughly) ordered by size. More complex systems are built up by aggregating stable subsystems. There are more and more "degrees of freedom".[2] Interactions across levels can cause massive changes in behavior. As a result, interactions across levels become messier and messier.

The meta-theory structure that I am proposing is meant to produce common ground so that conversation can continue even while theorists deeply disagree about fundamental features of complexity. This framework presupposes that the overarching functions of CPMs can't be fully parsed in terms of any one of the sciences of complexity in the list, nor

[2] By "degrees of freedom" I do not mean radical or "metaphysical" freedom – the view that you can choose your next action without being strongly constrained by the sum total of causal inputs on you since birth (and before). "Degrees of freedom" refers to the possibility space that describes the sum total of possible actions for (say) an organism.

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by a single overarching science of complexity that explains all complex systems using a single mathematical model. The common features of CPMs can only be discerned through comparative studies of how they function in what are in fact highly distinct empirical fields of study.

Three features mark the resulting discussions:

- multiple specific studies of complex systems are included, and the distinct dynamics of these specific fields become part of the analysis;
- any generalizations that are drawn are adequate to the whole range of the contributing fields of study;
- the resulting theories of complexity include similarities across specific subfields, even when they are not shared by all the fields involved. There may be regional laws, but at this point there are unlikely to be laws that subsume all the fields being analyzed.

Some critics have alleged that meta-theories of this sort are inherently unstable; they must collapse into separate regional sciences, or give rise to a single overarching science of complexity, or move permanently into the sphere of philosophy. But I disagree. The creative tension produced by meta-theoretical analyses of this sort is constructive for the growth both of science and of philosophy. Think of suspended chords in music: the ear wants to quickly resolve an F-major chord where the A is replaced by a B-flat. But the suspension is musically productive; it moves us along. So likewise here. Since the Greeks, we have recognized the role of "heuristics" in empirical research.

The meta-theories framework is especially effective when one encounters "take-over bids" from one or another participant or discipline in this discussion. It helps to resist the claim that one particular area of specialization will finally subsume all the other disciplines until sufficient evidence is in hand to decide the question. Of course, focusing on such a wide range of disciplines can create tension. But it also reminds us that we are working at the frontiers of what is known (and perhaps what is knowable). Generalizations that provide a sense of "the lay of the land" – even when they move beyond what can be established scientifically – continue to be helpful when one returns to his or her home discipline.

For example, there is evidence that co-evolution can also occur between biological processes and cultural learning. In an influential book, William Durham (1991) argues that natural history reveals a dual inheritance system, involving networks of cultural as well as genetic

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transmission that function in continual interdependence. To take a simple example, at one time most human adults could not absorb lactose, the sugar found in milk, from non-human mammals. Today a much higher percentage of adults can absorb lactose from various milk sources, although this ability varies dramatically across populations. The evolution of the enzymes for absorbing lactose is, of course, a biological process. Yet a wide variety of cultural factors have also crucially influenced this outcome, including access to fresh milk, the practice of herding animals, the development of dairying technology, and whether drinking fresh milk is valued and encouraged within a particular culture. All these cultural practices have promoted the biological evolution of lactose tolerance in adults. Evolution of that biological capacity has in turn encouraged the further development of these particular cultural practices, in an ongoing spiral of mutual influence.

14.3 Implications of the "multiple complexities" approach

Eight theses follow from or are suggested by the argument to this point.

(1) The definition and explanations of agents in a complex system are inseparable from the dynamics of that system. To be a unicellular organism is to be the sort of entity on which natural selection operates. Actions by biological agents of this sort only make theoretical sense when biological dynamics become an explicit part of the account.

(2) This makes organisms meta-level agents, analogous to the meta-level theory of complexity defended in this chapter. A complex organism depends on the biochemistry of its hemoglobin, the biomechanics of its physiological structures, the mechanisms that maintain homeostasis, and the neurological patterns that allow mental representations of its environment. Yet, despite the complexity of these many layers, it frequently acts as a single, unified agent in its environment. Evading a predator, it springs either left or right – and either survives or dies as a single unit.

(3) The laws of physics are necessary but not sufficient for explaining the nature and interactions of biological agents. There is an asymmetry here: Darwinian explanations must be consistent with the laws of physics, but the general laws of biology (if such exist) do not similarly constrain the motions of all physical particles. Although saber-toothed tigers, salesmen, and soccer teams consist

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of the same mass and energy that physicists study, their actions remain unexplained without the concepts and patterns of biology, psychology, and sociology respectively. No laws of physics are broken by these higher-order complex systems, just as no laws of physics are broken when the motion of the atoms in the rim of a wheel is explained in part by that wheel's rolling down a hill (and that motion explained, in part, by the intentions of the driver).

(4) These non-symmetrical relations between disciplines of study produce the "ladder" of the sciences. This ladder is temporally indexed and corresponds to the order of cosmic evolution.

(5) Later fields of study in the process contain all the complexities of earlier field while adding new forms of complexity of their own. We thus encounter (what intuitively appears to be) increasing complexity as we move from physics to biology to psychology. *Pace* Descartes, mental complexity presupposes and builds from complex neural systems, even though the complexity of brains isn't enough by itself to fully explain how and why systems of mathematics or philosophy are complex in the specific ways that they are.

(6) Forms of complexity that arise later in the evolutionary process do not function independently; emergent systems rely on the complex systems available to them to further complexify a given organism or environment. The human brain, with its around 10^{11} neurons and some 10^{14} neural connections, is arguably the most complex natural system we have yet encountered in the Universe. It is not surprising that it would produce mental systems complex enough not only to invent neurology but also to invent the symphony and the Italian sonnet. On the other hand, complexity does not increase in a simple, straight-line fashion. The thought of justice or world peace need not be more complex than the male's thought of the female with whom he wishes to copulate. Emergent properties are not always more complex than the systems that produced them.

(7) To pluralize complexity studies, as the CPM approach does, does not block the natural scientific study of the world but enhances it. There is more, not less, "natural piety" in emphasizing the differences among complexity-producing mechanisms, and thus the differences among the agents they produce and the actions they carry out. And there is less scientific rigor in construing all dynamical systems within the context of a single framework, à la Newton, in those cases where the differences between subsystems are essential to explaining them fully.

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(8) CPMs are of course not independent. They build on one another, producing compound effects that individual CPMs could never produce. From an evolutionary perspective, there is often a selective advantage of CPMs running on CPMs. It would be unwise for a human engineer to attempt this strategy, since the outcomes would be unpredictable and he would lose control of his design. But evolution does not work by design; it works best when there is a profusion of genetic (and thus phenotypic) options that natural selection can go to work on. The method of CPMs running on CPMs has been extraordinarily effective at developing complex organisms and ecosystems – life as we know it on this planet.

14.4 PHYSICS, BIOLOGY, CULTURE

Given the "multiple complexities" approach, one would not expect biological complexity to be identical to the complex systems that we encounter in physics. The study of evolving systems supports this conclusion. Darwinian explanations depend on selection, fitness landscapes, and the structures and functions to which they give rise. These do not appear to be dynamics that one can model in (say) thermodynamic terms alone (Kauffman & Clayton, 2006).

Systems biologists identify distinct levels in the complex systems that they study. Consider, for example, what is entailed by conceiving a cell, organ, or organism as a dynamical system. In *Closure: Emergent Organizations and their Dynamics*, Cliff Joslyn (2000, p. 71) argues "One crucial property entailed by closure is hierarchy, or the recognition of discrete levels in complex systems. Thus, the results of our discussion can be seen in the work of the hierarchy theorists . . . A number of systems theorists have advanced theories that recognize distinct hierarchical levels over vast ranges of physical space. Each of these levels can, in fact, be related to a level of physical closure . . . that is, circularly-flowing forces among a set of entities, for example among particles, cells, or galaxies . . . "[3] Lemke (2000, p. 100) adds "Certainly for biological systems, and probably

[3] The hierarchy language was rather more pronounced in the early phases of systems biology. Thus Auyang wrote in a classic text "Our sciences present the world as a hierarchical system with many branches, featuring individuals of all kinds. The individuals investigated by various sciences appear under different objective conditions . . . All individuals except the elementary particles are made up of smaller individuals, and most individuals are parts of larger individuals. Composition includes structures and is not merely aggregation" (Auyang, 1998, p. 40).

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for many others as well, the richness of their complexity derives in part from a strategy that organizes smaller units into larger ones, and these in turn into still larger units, and so on."

The way in which higher-level functions constrain phenomena at a given level (say, proteomics) represents a distinguishing feature of biological systems. As Bernhard Palsson notes, "It is not so much the components themselves and their state that matters, contrary to the components view, but it is the state of the whole system that counts . . . We cannot construct all higher level functions from the elementary operations alone. Thus, observations and analyses of system level functions will be needed to complement the bottom-up approach. Therefore, bottom-up and top-down approaches are complementary to the analysis of the hierarchical nature of complex biological phenomena . . . There will be additional constraints and considerations that arise as we move up the hierarchy. Thus there may be measurable changes at a lower level that are inconsequential at a higher level" (Palsson, 2006, 13–14, 22–23, 284). Arguably, reconstructing how specific interactions between these different levels of analysis work lies at the very center of understanding biological systems.[4]

When one moves to the study of complexity in cultural systems, a new set of contrasts arises. Cultural complexity does not arise in the same way biological complexity does, nor can it be studied in the same way. Cultural explanations are fundamentally Lamarckian, in that acquired cultural characteristics are passed from generation to generation through social learning. They also depend (in part) on the culturally transmitted influence of new ideas and theories, the power dynamics of competing groups, the personalities of charismatic leaders, and the conscious intentions of agents. These are not dynamics that we can model in the same ways that we model the dynamics of Darwinian systems.

Of course, biology holds culture on a leash.[5] When the Shakers' beliefs cause them to stop reproducing, they won't be biologically successful. But it has turned out that the leash is much longer than the early sociobiologists thought. If a (non-reproducing) priestly class is culturally powerful enough, it may attract enough new adherents that it

[4] According to the biosemiotics school (e.g., Jesper Hoffmeyer and Carl Emmeche in Copenhagen), emergent levels hierarchically interpret the levels below them and emit signs of their own, which can be interpreted across hierarchically emergent levels. See, for example, Hoffmeyer (2008).

[5] E. O. Wilson famously identified the biological influences on animal and human behavior as a "genetic leash" in *Consilience* (1998, 127–128).

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outperforms normally reproducing segments of society. (Some cheating is presupposed, of course.) Hence biological explanations aren't sufficient; explanations given in cultural terms do some explanatory work that can't be done without them.

The distinctive patterns of spontaneously emergent, complex order in cultural systems are studied by social psychologists, sociologists, economists, and cultural anthropologists, among others. In the study of cultural systems explanations in terms of laws play a rather smaller role. The emphasis tends to lie instead on explaining the distinctive features of individual projects and specific historical outcomes. Social scientists thus contrast "idiographic science" – the study of individual events, individuals, and epochs – with "nomothetic" or nomological (law-based) sciences (Lindlof, 2008). Succeeding in this explanatory task requires empathetic understanding (*Verstehen*), as Wilhelm Dilthey famously showed (Dilthey, 2010; Clayton, 1989). That is, one must rely on experience or "insider's knowledge" in order to formulate hypotheses and interpret data.

This is not to say that biological laws are irrelevant or that there are no laws of human behavior. But laws generally turn out to be effective for only a subset of research questions, such as predicting the behaviors of a mob or analyzing the purchasing behaviors of large groups of consumers within a given time span and culture. Only then can we make the assumption that humans will act as "ideally rational" economic agents.

It has been standard to refer to cultural patterns, artifacts, and ideas as "epigenetic". In one sense, of course, the term is unobjectionable; we are clearly dealing with phenomena above the level of genes and their direct effects. But to refer to culture as a whole as "the epigenome" is misleading in several respects. Firstly,[6] it's not clear what are the "substrates" in cultural evolution, for example of writing systems (clay, papyrus, printing press, computer files, etc.). Secondly,[7] cultural creativity seems to be an exception to the absolute biological limits that elsewhere constrain species development. There are multiple limits on brain capacity, but not on mental performance (think of mathematical discovery).

More broadly, treating culture as the epigenome leads one to look for analogies with genes and their products, when in fact the cultural phenomena in question are highly *disanalogous* to the genetic transmission of information. There certainly are patterns to be discovered within cultural products such as literary styles, schools of art, the "ethos" of

[6] David Krakauer made this point in conversation at the complexity symposium in Phoenix, AZ in 2010.

[7] I owe this argument to Simon Conway Morris at the same symposium.

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a culture, or different religious traditions, just as there are clearly contrasts between different mental representations. But the similarities and differences between cultural products like these require very different forms of research and testing than in physics, chemistry, or molecular biology.

14.5 Complexity and the "big questions"

In discussions with scientists, and thus in volumes such as the present one, philosophers play two different roles: one that is oriented primarily toward the sciences, and one that turns its attention beyond them. In the first, philosophers help bring conceptual clarity to the challenges and the possible solutions within a given discipline, essentially playing a service role to the scientists who are working to move their discipline forward. The other role is to think rigorously about the questions at the borders of, and finally beyond, the existing sciences.

The meta-level theory of complexity that I have explored here includes components from both roles. In many ways it turns attention back to the study of specific complex systems, though it also encourages reflection on the more general patterns – the similarities and differences across the sciences – as a point of orientation for doing specific scientific work. But it can also turn attention in the other, more speculative direction, asking more purely philosophical questions about the meta-theoretical features of complexity as it is manifested in specific natural systems.

Neither the specific scientific work nor the more speculative questions are privileged, and neither should exercise hegemonic control over the other. The tragedy of the last decade (if I might editorialize for a moment) is that productive partnerships between scientists and philosophers have been rather on the decline, spotlighting instead the more domineering voices in science on the one side and the anti-scientific voices in religion on the other, each fighting to take control of the battlefield. Some now view with suspicion any collaborative efforts with philosophers, fearing a metaphysical take-over bid. The more subtle (and more productive) work – the work in which both detailed science and speculative reflection contribute as partners – is a more vulnerable form of discourse and is easily destroyed by such hostilities.

I close then by mentioning a few of the "big questions" that are raised by contemporary discussions of complexity, moving from the descriptive to the clearly metaphysical. Even if these questions can't be discussed here, it is worth noting some of the philosophical topics that

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the broader discussion of complexity raises when one follows its natural trajectory.

- Descriptively, it appears that this cosmos functions in such a way that complexity is increased. It is also a complexity that is non-algorithmic and open-ended. Unlike thermodynamics, we have no second law of complexity, so we do not yet know whether the increase in complexity is a necessary feature of this Universe.
- The growth in complexity is of course depending on certain fundamental features of the physical Universe. It is highly unlikely that complexity would increase in a Universe in equilibrium, just as it is highly unlikely that complex life forms would evolve if the planet were not bathed in radiation, that is, in a far-from-thermodynamic-equilibrium state. Still, the dependence of complexity on thermodynamic conditions does not mean that thermodynamics is sufficient to explain the complexity that subsequently arises.
- The fields of study required to make sense of the full range of complexity-producing mechanisms include physical systems that one can model mathematically, chemical and biological systems, and complex neurophysiological systems such as the human brain. But they also include cultural, psychological, and intellectual systems, which are irreducible components of the complete explanation of human beings.
- Against Intelligent Design, I strongly resist using the label "science" to describe the speculations to which complexity may give rise. For example, there is no way to move up the ladder of the scientific disciplines (and the various types of complexity that they study) to produce a "scientific" proof of the existence of God as a Cosmic Designer of complexity-producing mechanisms.
- Nevertheless, one could intuitively feel that a Universe of increasing complexity is the sort of Universe one would expect if religious views of ultimate reality are correct. Indeed, one could correlate these religious views of reality with the Universe we observe and offer metaphysical accounts of the ladder of complexity. Again, such reflection is better understood as "faith seeking understanding" rather than compelling philosophical proof – much less as a sort of metaphysical science, which is a contradiction in terms. But one can do some fairly rigorous philosophy in the attempt to turn these intuitions into philosophical arguments. Those without an ear for rigorous philosophy of this sort – and especially those who have never read it – should not be over-quick in dismissing it.

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- Those with metaphysical interests begin with intuitions that are not universally shared. Intuitions should spawn deeper reflection. If one has intuitions of metaphysical purpose, one can attempt to explicate this intuition in philosophical systems (which are, I suppose, another variant of complex systems). Such systems can be either superficial or profound. Of course, one can also begin with the intuition that no such metaphysical purpose exists, and one can also develop that intuition into a broader philosophical account as well. Here also the answers given may be either superficial or profound.

The meta-level theory of complexity defended here is essentially open to discussions of this sort. Where these discussions will lead is, of course, another question.

> The ordinary-sized stuff which is our lives, the things people write poetry about – clouds – daffodils – waterfalls – what happens in a cup of coffee when the cream goes in – these things are full of mystery, as mysterious to us as the heavens were to the Greeks.
>
> When we have found all the meanings and lost all the mysteries, we will be alone, on an empty shore. (Tom Stoppard, *Arcadia*)

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