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The Disunity of Science and the Unity of the World Presidential Address, PSA 2022

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Abstract

This paper recapitulates earlier work in which I argued for the disunity of science, the plurality of partly incommensurable ways in which the world can be conceptualised for scientific purposes. It then aims to show how this plurality is intelligible, even to be expected, from the perspective of a process philosophy that sees the world as largely disorganised, but as allowing the emrgence of pockets of stability, most notably the stability provided by biological organisms. It incidentally aims to demonstrate the importance to one another of science and metaphysics.

Introduction: Science and Metaphysics

Much of my philosophical career has been devoted to the defence of the importance of metaphysics for the philosophy of science. Hence my title today, which combines a thesis in the philosophy of science with a thesis in metaphysics. This is not, however, exactly the kind of metaphysics that most philosophers understand by the term. In describing the epistemological foundations of metaphysics, Wikipedia says: "Metaphysical study is conducted using deduction from that which is known a priori."[1] Like many of my colleagues

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[1] I do not mean this definition to be taken very seriously (hence the choice of source). The proper definition of metaphysics is a highly contentious issue (see, e.g., van Inwagen, Sullivan and Bernstein 2023; Lowe 2002). It is not contentious that there are considerable differences in opinion about the relation of science to metaphysics, ranging from views that take metaphysics to be an entirely a priori exercise, and those, like myself, who see it as ultimately answerable to our empirical, and especially our scientific, knowledge of the world. Lowe, generally representative of the former view, writes that metaphysics "deals with the fundamental structure of reality…[and] goes deeper than any merely empirical science…[providing] the framework within which such sciences are conceived" (2002, v); "it does not typically appeal to experimental or observational data in support of its claims" (2002, 2).

in the philosophy of science, I am suspicious of such an activity. The naturalistic metaphysics that I recommend is conducted using eclectically various modes of argument, but is ultimately grounded in what is known a posteriori.

It is not my present aim to criticise the project of a priori metaphysics. However, I do think that metaphysics matters for science, and that the metaphysics that matters for science is naturalistic. Science, as many philosophers have observed, cannot function without an underlying set of assumptions about the world that it aims to understand. As elegantly expressed by the nineteenth century biologist and philosopher J. H. Woodger, "Metaphysics can be ignored but not escaped: physiologists who suppose themselves to be above metaphysics are only a very little above it – being up to the neck in it'' (Woodger 1929 p. 246). But while science requires metaphysics, the metaphysics they require requires science. The relationship between the two should be interactive, or perhaps dialectical. Scientific results may imply revisions of the metaphysics that those results assumed.

What then distinguishes metaphysics from science? The answer, I think, is generality and abstraction. Take, as an example, causation. There is no science of causation, but many different sciences give us information about what causes what. What are they telling us? Is it something about the production of effects or changes, or how our interventions can generate change? Is it something about regularities or statistical tendencies? And so on. Perhaps Kant thought the nature of causality could be deduced a priori, but most philosophers have disagreed. Hume argued from our a posteriori experience of colliding billiard balls to his famous ideas about causation as regularity and his ideas were refined a century later by J. S. Mill (1843) and more than a century after that by J. L. Mackie (1974). Mill introduced rules for reasoning about causality and Mackie produced a definitive account of the relation between individual causal relations and the universal regularities that supposedly underlie them.

This tradition of philosophical discussion of causation is grounded in empirical evidence, whether from science or everyday experience. But there is also something that seems to be taken as an a priori necessity in this tradition of thinking about causes, and that perhaps justifies seeing this as according with the Wikipedia account of metaphysics. This is the idea that whenever something happens there is a prior set of conditions that is both necessary and sufficient for its occurrence. The relation of this set of conditions to what we may casually

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refer to as ‘the cause’ is complicated, but it is this set of conditions that expresses the law under which this causal sequence falls. And it is the belief in such laws that underlies the still common assumption of determinism, and that motivates debates about reductionism, emergence, epiphenomena, supervenience and so on. Ongoing interest in such theses is especially clear in the voluminous literature derived from Jaegwon Kim’s (e.g., 2007) arguments about the necessity of supervenience. Very briefly, Kim points out that if everything that happens at the microphysical level is determined by universal laws, and everything is made of the items that constitute that microphysical level, then everything that happens at any level must ultimately be determined by these microphysical laws. In this paper I shall argue that this assumption of universal lawfulness is, first, inadequately justified and, second, has real consequences.

So one goal of this paper is to show, first, that metaphysics matters and, second that a metaphysics that matters can be grounded in empirical science. Meaning by ‘metaphysics’ just the very general and abstract views about reality just indicated, I believe that there is a dynamic interdependence between such general views and the specificities of scientific opinion. Specific scientific findings are what provide much of the evidence for metaphysical theses, but well-grounded metaphysical views can provide us with reasons for questioning or modifying particular scientific views.

To amplify these views I begin by distinguishing two extremely general metaphysical theses about the constitution of reality. These are by no means the only possible such views, but I choose them because one is still widely believed and the other is true. Or so I argue. The first I call, abusively, the billiard ball world.

Against Billiard Balls

The billiard ball world is the picture that found its canonical expression in the world of LaPlace’s demon, in which a sufficiently expansive intelligence can predict everything in the future—or indeed retrodict everything in the past—from a sufficiently complete knowledge of the relevant features—traditionally mass, position and velocity—of the fundamental constituents of the world, atoms or conglomerations of atoms.

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No one, of course, or almost no one, now believes that the world is literally composed of tiny billiard balls. Remarkably, however, the determinism that was most systematically articulated in the context of the billiard ball world remains alive and well; indeed, it seems to be the default assumption of many or most philosophers. This is not quite right. Nowadays philosophers speak more of the causal completeness, or closure, of physics (CCP). This does not exclude an indeterministic universe provided that whatever causes there are, be they deterministic or probabilistic, are grounded only in the microphysical constituents of the world; and that moreover, for anything that happens there is some such law that applies to it.[2] What the probabilistic version does do, in common with traditional microphysical determinism, is rule out the causal efficacy of everything else in so far as this is not merely a summation of the causal efficacies of microphysical parts. The strength of the hold of this idea is apparent in the widespread discussion of emergence, supervenience, reductionism and even free will. One canonical exposition of the consequences of CCP is Jaegwon Kim' argument for the causal exclusion of the non-physical, specifically the mental. There is much discussion of exactly how this is supposed to work, but much of this discussion takes for granted its fundamental premise, CCP.

There has been a good deal of debate about the status of CCP, and I shall not attempt to review this here. I will make just two comments. First, it is surely not a well-grounded empirical claim. The behaviour of microphysical particles is understood, explained, or predicted only in very specific, isolated and controlled circumstances. Physics laboratories, such as the massive particle accelerators like those including the vast machines at CERN in Geneva or the Brookhaven National Laboratory in the USA, are exceptional places. They have no doubt provided remarkable insights into the nature of the smallest known elements of matter. But to extrapolate such findings to the ultimate determination of everything in the universe is, to put it politely, a leap. Second, and related to this point, the truth or falsity of CCP is not immediately relevant to work outside the physical sciences. Exploring the metabolic processes in a cell, let alone the behavioural tendencies of a troupe of monkeys, has little to do with the behaviour of microphysical particles. Billiard ball metaphysics does, however, have some indirect effects on how we think about scientific problems. Perhaps the most obvious of these is the suspicion of downward causation, motivated by arguments such as Kim's exclusion principle. More generally, whereas bottom-up reductionism is quite

[2] For further discussion, see Dupré (1993), ch. 9.

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widely rejected as a genuine achievable ambition, it continues to motivate the assumption that explanation should generally run from part to whole. This, in turn, provides much of the motivation for the very popular new mechanism.

The first main part of my philosophical career was spent arguing against the billiard ball universe and a set of views often closely associated with it. These include: reductionism, the idea that ultimately science aims to derive explanations concerning complex entities from regularities concerning their constituent parts, or eliminate the former in favour of the latter; essentialism, the doctrine that facilitates links between the macro- and the micro-levels by identifying the microphysical nature of macrolevel objects; and determinism, already mentioned as a (perhaps the) core feature of the microphysical world. I criticised all of these doctrines in some detail in my 1993 book, *The Disorder of Things: Metaphysical Foundations of the Disunity of Science*.

The alternative view that I proposed at that time was that far from exhibiting the universal order assumed in the Humean tradition, the empirical evidence suggested that order was a very local affair. The notion that order was omnipresent derived from a natural, but excessive and misleading attention to the most prominent phenomena that exhibit a striking degree of order, organisms and machines. In early instantiations of the idea, most notoriously in the work of René Descartes, (non-human) organisms were taken to *be* machines, the work of a divine being who also, incidentally, made the all-encompassing machine in which these intricate living machines were found.

Pockets of order also emerge to some extent from the relations between bits of non-living matter. As Elizabeth Anscombe brilliantly observes in her inaugural lecture one such non-living system played a starring role in the emergence of modern Western science, namely the solar system. As Anscombe noted:

> "The high success of Newton's astronomy was in one way an intellectual disaster: it produced an illusion from which we tend still to suffer. This illusion was created by the circumstance that Newton's mechanics had a good model in the solar system. For this gave the impression that we had here an ideal of scientific explanation; whereas

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> the truth was, it was mere obligingness on the part of the solar system, by having had so peaceful a history in recorded time, to provide such a model". (Anscombe, 1971.)[3]

The disunity in this view follows simply from the fact that if there is no universal order out of which local pockets of order emerge, there is no reason to suppose that whatever uniformities apply to a particular ordered domain will apply to every such pocket of order. It is also vital to note that, absent this universal underlying order, it should be no surprise that even local order may well be only partial. This is the point of Anscombe's remarks on the solar system. To give another rather gruesome example, the refusal of biological nature to be fully orderly continues to defeat the efforts of mass producers of pigs to produce animals sufficiently uniform to allow their disassembly in abattoirs to be fully automated (Blanchette 2020).

This view also has consequences for science. The rejection of the metaphysics that reductionism assumes (as opposed to reductionist methodology, to which I'll return) defuses often unhelpful assumptions that the only ultimately acceptable source of understanding is reductive, in terms of parts. Attribution of distinctive properties to complex entities is always only provisional and always somewhat problematic. While reductionism in its strongest metaphysical versions has receded in recent years it now motivates less ambitious theses of mechanism, which at least generally maintain the idea that proper scientific explanation is always bottom up.[4] Rejecting such doctrines opens up new directions in explanation and understanding.

Reductionism is, to use an unfortunate term, the essence of the billiard ball world. The role of essences is a little more subtle. However, in so far as belonging to any structurally complex kind explains the behaviour of anything, it must be because members of that kind have some

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[3] A rather beautiful illustration of this point is provided by Cixin Liu's (2014) science fiction novel, *The Three Body Problem*. Part of the story is set on a planet under the influence of three stars, and the sequence of sunrises, seasons, and so on, is of course entirely impossible to predict.

[4] Alex Rosenberg (2020) describes mechanism as "reductionism with a human face". While contemporary mechanists generally deny that their view is reductionist, or even that it mandates bottom-up explanation, without these implications, and generally also denying any weight to the suggested analogy with machines, it sometimes seems that "mechanism" is degenerating into little more than a synonym for scientific explanation (Dupré 2013).

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common microphysical structure; it is very natural to say that the behaviour is a consequence of the microphysical essence of the kind.[5] A proper empiricism, on the other hand, not hampered by this metaphysical commitment, should always take the extent of homogeneity within a kind, whether structural or behavioural, to be a question for open-minded investigation.

Questions about essences, at any rate, continue to contribute not only to scientific dead ends, but also to social and political strife. Biology is full of examples. Despite not only decades of evidence for the diversity of kinds of species, but also a theoretical argument that the variability required for evolution to occur is inconsistent with individual species, it is still not unknown for scientists (or philosophers) to ask, what is the true nature, the essence, of the species or of a species.[6] More directly malign, and still very much alive in some areas of academic discussion, are essentialist assumptions about human kinds, notably races.

Perhaps ultimately more scientifically significant are the ways that these ideas have played out in molecular biology, notably for the two most prominent classes of biological macromolecules, genes and proteins. Whether or not there is an essence of a protein or a gene as such, when a particular molecule has been distinguished and its molecular structure described it is still often supposed that we have the essence of the molecule from which its behaviour, its unique function, will flow. The history of ideas about genes, evolving from the assumption that particular bits of sequence provided the casual origins of a vast array of particular phenotypic traits, to the current understanding of DNA sequence as a resource that can contribute sometimes to thousands of distinct proteins which, in turn, may function in numerous different metabolic processes, is well-known (see, e.g., Gayon 2016; Keller 2000; Barnes and Dupré 2009).

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[5] If there are no higher level kinds with essences, it remains metaphysically possible that the behaviour of each individual (a singleton kind) could be explained in terms of its parts. This is not a view with much epistemic bite.

[6] In a series of papers (e.g., Devitt 2008), and more recently a book (Devitt 2023), Michael Devitt has attempted to overturn the consensus among philosophers of biology that essentialism in biology is stone dead. I am unpersuaded of the rationale for this attempt.

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The evolution of thinking about proteins is remarkably parallel. Proteins are still widely considered to be the pre-eminent functional molecules in biological systems, and their functions—whether catalysing metabolic processes or providing the physical substance for various tissues—are, it is assumed, a consequence of the structural essences of the molecules. But just as bits of DNA turned out to do different things in different contexts, so with proteins. The behaviour depends not simply on the supposed internal essence, but on the relations between a molecule and its chemical environment.[7] Since proteins were often discovered precisely in the context of a search for the molecule that performed a certain catalytic or structural function, the disquieting revelation that it could do something different was memorably described as a case of "moonlighting" (Jeffery 1999, 2018). The molecule found something different to do on weekends or on its days off. A database of moonlighting proteins (MoonProt[8]) lists several hundred examples. Now proteins are known with up to a dozen different roles—though with a caveat that counting roles is not a very clear or even well-defined process.

Finally on this topic, I must mention intrinsically disordered proteins, proteins that lack a fully defined structure. These proteins exist in a suite of different conformations, rapidly switching between these, and settle on a particular structure only when induced to do so by their interaction with a relevant substrate. Nowadays it is said that in eukaryotes about 10% of proteins are fully disordered, and 40% have at least disordered parts. Fortunately, neither the numbers nor the meanings of these terms matter very much. The point is just that this is an example of a phenomenon far removed from the distinct entities with specific structures determining specific functions that are at the core of the billiard ball world understanding of complex entities.[9]

It is worth noting that from an evolutionary point of view the kind of flexibility I have briefly described is clearly an excellent idea. In the highly unpredictable world which is ours, the best strategy for survival is often adaptive flexibility. At the whole organism level, adaptive

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[7] For further discussion of the nature of macromolecules, and specifically proteins, see Guttinger 2021; Stein 2006.

[8] http://www.moonlightingproteins.org

[9] For a much fuller account of these phenomena, and arguments that these require understanding from the perspective of a process ontology, see Güttinger 2021.

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flexibility means behaving in ways that are appropriate to the particular situation an organism encounters. At the internal, molecular level adaptive flexibility will generally mean using the resources available to achieve the outcome needed at that moment. Clearly, genes that can contribute to producing a multiplicity of proteins, and proteins that can serve different functions in different contexts, will greatly enhance the possibility of such flexibility. It is no surprise that we should find exactly these sources of flexibility in the living world, or no surprise, at least, unless one is committed a priori to a metaphysics that rules them out.

To summarise the preceding point, in the traditional billiard ball world, structure explains function. This is also a central assumption implicit in the machine metaphors imported into biology by mechanism. Machines are an assemblage of parts put together in such a way as to generate a desired behaviour of the whole. But in biology function equally explains structure; not just in that a structure exists to perform a function, but that many or most biological functions exist to create and maintain the structures that perform them. As J. S. Haldane wrote almost a century ago:

"*Structure and functional relation to environment cannot be separated in the serious scientific study of life, since structure expresses the maintenance of function, and function expresses the maintenance of structure*" (Haldane, 1931, p. 22.)

In my 1993 book I argued that the fact that science presented us with disunified sciences provided compelling evidence that we did not live in the billiard ball world (specifically, a deterministic and reducible world). Very simply, if we lived in the billiard ball world, we should expect a unified science, ultimately reducible to the behaviour of billiard balls. But our science is nothing like this; so we don't live in the billiard ball world. In fact, I concluded at the time, we live in a largely disordered world in which under special circumstances we find that there are occasional pockets of order.

I still largely accept this conclusion. But whereas in 1993 I was inclined to take this as a brute description of the world about which probably not much more could be said, now I see it as the expected consequence of a general metaphysical view, a Heraclitean world of change and process. This is the unified world of my title: there are no things and, a fortiori, no atoms, there is, as Heraclitus taught us, only change. Within this change we can, however, distinguish processes.

Processes are of various kinds. Some seem to be necessarily attached to stable things: animals grow; cars rust. Others don't require any thing, though sometimes we invent one, as when we attribute inflation or growth to "the economy". Others do not even *appear* to need such a subject; we have no need of a referent of "it" when it is raining. But what of the animals (and ultimately even the cars)? My thesis is that these are themselves a kind of process, that what seem to us to be things are in fact temporary patterns in the universal flux, maintained by further processes, a kind of eddy or vortex in the flux of stuff.[10] Though temporary, they may persist for relatively long periods. Trees may last for millennia, for instance. So, despite some objections from more traditional metaphysicians, I consider such entities to be processual continuants.[11]

The Disordered World, or The Chaotic World with Islands of Partial Order

The default state of the world, I suggest, is a largely disordered flux. Patterns with more or less causal order may emerge under appropriate circumstances. These are more or less persistent processes (eddies in the flow) often with novel capacities. Their persistence and capacities may depend both on the capacities of their parts, thus sometimes allowing reductive or mechanistic explanation, but also on their embedding in larger systems. There is no uniform underlying order motivating generalized reduction, supervenience, determinism, epiphenomenalism, etc.

A good place to begin motivating such a view is with our current understanding of the history of the universe. Current cosmology describes the emergence of relatively stable forms after the Big Bang. Although there is some serious disagreement, especially about the

[10] For more detail, see, e.g., Dupré 2020.

[11] Philosophical orthodoxy distinguishes individuals into continuants and occurrents, and assigns processes to the latter category. Occurrents, in this scheme, differ from continuants in having temporal parts. Rowland Stout (2016), however, argues that processes can be both continuants are occurrents. Helen Steward (2013) disagrees, but does defend the view that there are processual individuals. The debates here are also entangled with that between endurantist and perdurantist accounts of identity. Detailed discussion of these issues is beyond the scope of this paper. For a view of processual identity congenial to the present account, see Meincke 2019. For a range of perspectives on biological identity, see Meincke and Dupré 2020.

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unimaginably rapid inflation that is supposed to have occurred for perhaps 10^{-36} seconds after the big bang, the general outline seems remarkably widely agreed. The momentary aftermath of the big bang was a universe containing entirely disorganized energy. After about 10^{-12} seconds, quarks, gluons and electrons appeared. After 10^{-6} seconds, with the temperature having fallen to around one trillion degrees, quarks and gluons combined to form baryons, neutrons and protons. In about ten seconds, small nuclei (deuterium, helium) emerged, and in a few hundred thousand years the first atoms appeared. In some hundreds of millions of years gravitation and irregularities in the distribution of matter led to the appearance of stars. And so on.

The details of this story are not important. What matters is the overall outline, which is of a series of temporarily more or less stable structures with capacities to combine into larger, but still only temporarily, stable structures. Some of these, like stars, have reasonably determinate life cycles. Some, like protons, are extremely stable, though physical theory requires that they can decay under some circumstances. Electrons are said to have a mean lifetime of at least the order of 10^{29} years. Neutrons, by contrast, are stable only when bound in a nucleus; free neutrons have a half-life of about 15 minutes.

The point of this is just to insist that the main story I want to tell, about life, is prima facie quite continuous with the history and composition of the physical world. After many billions of years a new kind of system emerged from the background chaos: life. As Richard Dawkins has rightly stated, evolution is most generally not the survival of the fittest, but the survival of the stable. And this characterization applies as much to the physical universe as to the living world.

Life

Life, anyhow, is composed of *processes* temporarily *stabilized* from the flux of biological activity. By contrast with machines[12], the stability of an organism is not a default but an

[12] I shall not dwell here on the fraught relationship between machines and mechanism. Mechanists nowadays tend to say that there is no relationship beyond an accident of etymology, though their work is often nicely illustrated with pictures of machines. Elsewhere I have suggested that new mechanism sometimes flirts with vacuity as it steers away from the

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achievement[13], something the organism is constantly working to maintain. An organism cannot be switched off and stored (though the simpler ones can sometimes be slowed down enough by deep freezing that they will last a long time doing very little). Methodologically, the most general implication of a process perspective is that it is very often persistence rather than change that requires explanation.[14] Life is flux, and living systems are eddies within this flux.

Here I shall focus on the organism. Similar arguments apply to other levels of biological organization, but the organism is the most familiar kind of biological system, and will well represent the general claim. There are at least three compelling reasons for understanding organisms as processes, as more or less stable structures (eddies) within the flow of living activity.

First, organisms are metabolic processes. As is often remarked, organisms are systems far from thermodynamic equilibrium. To maintain this condition they require energy from the environment in the form of food, oxygen, light, etc. The flow of these materials into the body and the excretion of materials with lower energy content provides the requisite energy. When this flow ceases the organism dies and eventually the system regains thermal equilibrium with its environment.

Second, an organism is a developmental process. Organisms have life cycles. Or, as I prefer to say, organisms *are* life cycles. As we all know, organisms go through a series of different stages, for example as egg, tadpole and adult frog. We generally assume that one organism goes through these stages. It is implausible in such a case that at some point in this sequence

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limitations of traditional machine analogies and embraces pretty much whatever kinds of explanations the life sciences throw up (Dupré 2013).

[13] I should also add that of course there are many ways that machines may be designed to be more stable in operation. The point is that they can generally be stabilised by the simple act of turning them off.

[14] One example I like to use for this is the science of cancer, wherein it may well be a more profound problem why multicellular organisms often do not suffer from cancer rather than to provide any general explanation of why they sometimes do (Bertolaso and Dupré 2018).

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the organism goes out of existence and is replaced by a new one. But this presents a problem for view of the organism as a thing. For the egg has very little in common with the frog beyond the continuous process that causally connects them. There is no essential property that underwrites the claim that these are two temporal stages in the career of one and the same thing.

The solution to this problem is to see that the organism is not a thing but a process. The causal continuity just referred to is all there is to its continuation over time. An obvious consequence of this claim is that identity over time is always a matter of degree; there is no a priori limit to how much change may occur within a continuing process. The rejection of the identity of a thing over time as an all or nothing matter is surely a positive payoff for process philosophy. The divisions, mergers and developmental or evolutionary changes that occur throughout biology cease to present any deep philosophical worries. It may also seem disturbing, especially, no doubt, the loss of personal identity over time as an all or nothing matter. Without going into much detail here, I will note only that I feel entirely sanguine on the point. Philosophers are wont to say that a person is, at any moment, "wholly present", apparently a state incompatible with being a temporal part of a process. I'm not at all sure I understand what this means. Was I wholly present at the moment of my birth in just the same sense as I am today? I believe that I am part of the same process as that infant, but there seems very little else that we have in common.[15]

Third, almost all organisms are to some degree symbiotic. That is to say, their persistence requires continuous interaction with other organisms. I should stress "requires" and "continuous". Familiar symbiotic interactions between, for example, a cleaner fish and its clients are mutually beneficial, but neither continuous nor perhaps strictly necessary for either party. I am thinking rather of the interactions between almost all multicellular organisms and the host of microbes with which they interact; or the relations between the microbes that make up multispecies communities such as microfilms. The problem here is that where these

[15] Extensive discussion of the questions alluded to here can be found in Meincke and Dupré 2022, which includes chapters by both philosophers of biology and analytic metaphysicians. Both editors explicitly defend a process view of identity. A related perspective grounded in the so-called organisational view of life is presented by Moreno (2018) and by DiFrisco and Mossio (2018) in the same volume. All of these have strong affinities with the concept of genidentity, originating with Lewin (1922), and elaborated more recently by Pradeu (2018).

relations are indeed necessary and continuous, it becomes quite unclear where to draw the boundary around the organism. Are your gut bacteria part of you or just further organisms inexorably yoked to you (see, e.g., Dupré and O'Malley 2009; Suarez 2018)? One may even ask the same question about the relation of an embryo or foetus to the mother, though here there is a directed process of separation (Meincke 2022).

My point here is not to answer these questions, but to suggest that in a traditional substance ontology it is hard even to think about them clearly. The reason we are tempted to think of our gut microbiomes as parts of us is that they, or anyhow some of them, are constantly involved in sustaining our stable existence. But substances are supposed to be stable by default, self-maintaining. This might suggest that we move quickly to the answer that they must indeed be part of us. But then we must ask, How vital for our persistence are particular microbes? It looks as if there is a spectrum from the necessary through the beneficial to the pathological. And in fact where a microbe lies on this spectrum may be highly dependent on circumstances, such as its location in the organism (Méthot and Alizon 2014).

What symbiosis tells us is that the boundaries of the organism are fluid and not fully defined. Constituents of living systems come and go, and their role in the larger system may change. The stability of a pattern in the flux of living activity and interaction depends on activities at the borders that neither clearly do nor do not belong to the pattern. Substance or thing ontology sees a system such as an organism as a discrete entity distinct from this surrounding flow. But this fits ill with life as we have come to know of it. Ultimately, the boundaries around living systems are drawn by us, not by nature. They are not arbitrary, but neither are they fully determined.[16] This presents no problems for a process ontology.

I take each of these reasons to be good and sufficient for treating organism as processes. Together they provide a compelling argument for this move.[17]

[16] I sometimes refer to the indeterminacy of the boundaries of individuals as "promiscuous individualism" in parallel with the promiscuous realism that I proposed as a theory of natural kinds in Dupré 1993.

[17] For more detail on organisms as processes, see, e.g., Nicholson 2018; Dupré 2020.

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Viruses

The more philosophers of science have turned their attention has turned to engagement with the details of real scientific research, the more they have tended to avoid abstract arguments at the level characteristic of metaphysics. In light of this situation, and in the hope of allaying such suspicions, I want to conclude with a little detail on how a process metaphysics provides genuine and even practically applicable insight into a real question, the nature of viruses.

By way of introduction to the topic, let me note that while the typical human hosts about 10^{14} symbiotic cellular microbes, they also provide a home for about ten times that number of viruses. Viruses are everywhere; they are by far the commonest living systems on our planet.[18] So what are they? It is common to identify the virus with the virion, the largely inert state of the virus when it is not actively infecting a cell. The virion is the entity that we spray around us when we have respiratory infections, and which we fear encountering on door handles and from handshakes.

But if the virus is the virion, it ceases to exist when it infects a cell. In this active phase of the virus life cycle, the virion inserts itself into a host cell membrane and then inserts its genetic material into the cell. From then on the virion, as such, no longer exists. A series of chemical interactions take place including the coopting of the host's protein translation machinery to produce viral proteins. These, finally, reassemble into virions, and in most cases the host cell is lysed—destroyed—and the virions released. During this active phase there is no virion and no other object that provides a plausible candidate for the thing that is the virus. The solution is to recognize that a virus is a process, and only in a particular phase of the process is there any plausible candidate for a thing that could be identified as the virus.[19]

Does this matter? I believe that it does. First, it seems likely that thinking of the virus as a flow of biological activity deeply intertwined with other symbiotic processes reduces the

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[18] There remains some debate as to whether viruses should properly be counted alive. Frequently the argument that they should not is based on the premise that their continuation depends on other organisms—a very weak argument as the same can be said of just about all organisms (Dupré and O'Malley 2009). The issue is of no importance to the present discussion.

[19] For more detail and further references, see Dupré and Güttinger (2016).

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temptation to think of the virus as an isolated entity with its own unique goals and motivates a question whether viruses may often have benefits for these larger symbioses. This seems increasingly clearly to be the case. As mentioned, there is an enormous number of viruses in a multicellular system such as ourselves, and just as with symbiotic bacteria, it would be remarkable if none of these played any but a predatory role in the system. This thought is reinforced by the observation that the population of viruses seems fairly stable. If they were merely predatory one would expect oscillations in population of the kind famously captured by Lotka-Volterra models (see, e.g., Reyes 2010).

Scientists have not struggled to find plausible functions for viruses in complex multispecies individuals. One obvious thought, given that the large majority of such viruses are phages, viruses whose hosts are bacteria, is that they serve to regulate the numbers of symbiotic bacteria. They may also serve to protect against pathogenic bacteria, a thought encouraged by the discovery of dense concentrations of phages on mucus tissues (Barr et al. 2013), the sites where encounters with dangerous bacteria are most likely. It has been known for some time that latent herpesvirus infections can protect against some serious bacterial diseases (Barton et al. 2007). And it is thought that viruses may provide storage of bacterial genetic variability that can be deployed when needed, for example, for antibiotic resistance (this, of course, having various potential costs and benefits for different participants in the system).

Thinking of the viral flow passing through organisms may also be highly productive by diverting attention from the individual virion. Virus populations appear to have an optimal level of diversity associated with their relationship to a particular host, and populations with an equilibrium level of diversity are known as viral quasispecies (Schneider and Roossinck, 2001). Higher variability enables the quasispecies, the viral flow, to adapt to diverse new host interactions, and it may present greater challenges to the host immune system. To maintain optimal variability requires an appropriate mutation rate, but since, it is assumed, mutations are generally deleterious, too high a mutation rate will be harmful to the maintenance of the flow. This has even led to the exploration of so-called lethal mutagenesis, the use of drugs that increase viral mutation rates, as a possible viral therapy (Bull et al. 2007). I am not proposing that thoughts of this kind are in principle inaccessible to someone wedded to the idea of the virus as a substantial individual. But they surely fit more naturally within the framework of viruses as constituting a flow of activity moving within or through the host.

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This paper has so far been concerned primarily with metaphysics, or ontology, for which I make no apology. However, as colleagues, especially those more sceptical about metaphysics often suggest to me, what we really need is a process epistemology. We don't need to be told merely of findings that support a process ontology, but also of how a process perspective helped us come by these results. I do believe that a sharp distinction between metaphysics and epistemology is misplaced. Surely how we investigate the world will be significantly affected by what we think it is. But the expectation that I should say something about *how* our investigations might be improved by the adoption of a process ontology would affect scientific practice is entirely reasonable. Here, retaining the specific focus on virology, I offer some very brief thoughts in this direction, grounded in experience of the recent Covid-19 pandemic.[20]

Virology provides an excellent illustration of the importance of a process perspective as viruses are not only very rapidly changing processes, but are also embedded in lineages. The very rapid evolution of these lineages both within an infected population and within an individual host raises difficult methodological problems. The static description e.g., of a particular variant, is an abstraction from this process, what we have called a *reification*.[21]
The erroneous identification of reifications of processes with stable things can lead to many kinds of error. Think, for example, of the interactions between variants, testing regimes and transmission rates in the Covid-19 pandemic. All of these are stabilized: as variant names (with associated testing criteria); as locally current packages of criteria for administering and recording particular tests; and in applications of the latter to estimating prevalence and transmission rates. But all of these are also evolving processes and failure to track their divergences led to numerous policy mistakes in the handling of the crisis. Confusion around naming hampered the attempts of researchers around the world to communicate their findings

[20] This section is based on joint work with Sabina Leonelli (Dupré and Leonelli 2022).

[21] Dupré and Leonelli 2022. In that paper we also distinguish between reifications as (1) means-reification (phenomenon-to-object), when researchers create objects such as data and models that are meant to capture features of the world at a particular point in time, or phenomena, in order to be able to study them; and (2) target-reification (object-to-phenomenon), when researchers infer an understanding of features of the world from an understanding of the objects created to study them (op. cit., p.4). For reasons of space, I shall ignore this distinction here; but it is essential for a full analysis of the topic under discussion.

to one another. This problem was exacerbated by the diversity of expertise engaged in the research, from taxonomists and genomicists to epidemiologists and public health experts, not to mention journalists and policymakers. It was difficult to know whether results or predictions emanating from these various sources referred to the same variant, or even, given the ever-changing diversity within viral flows, what should be meant by "same variant".[22]

This is not the place to say how these problems might have been better handled. But I think it is clear that greater awareness, in communication both to publics and between scientists, of the problematic status of such terms as "variant BA.4", would have been helpful. It is natural for most people to hear such a term as naming a kind of thing, and we were often informed that such kinds could be identified by geneticists. But the real reference of such a term is at best of a particular branch, or lineage, in an evolving process, and a description of the referent in terms of genetics is likely to be true only of certain constituents of certain phases of the lineage. Other changing elements in the lineage may be of equal or greater significance to the course of the pandemic.

Conclusions

Our thinking about life is often hampered by its grounding in the world view of the scientific revolution, eternal things pushing and pulling one another, or yoked together to form mechanisms. While I don't mean to suggest that contemporary scientists literally believe in the billiard ball world, important philosophical assumptions deriving from it are still often unquestioned. These range from an underlying determinism in nature to the assumption of homogeneous and essentially unchanging constituents of the phenomena scientists investigate. Such assumptions, I argue, have real and epistemically damaging consequences.

Process ontology provides the proper account of the disordered world that (disunified) science increasingly describes. The promiscuous realism and scientific disunity of my earlier work was a synchronic analysis; process ontology provides the diachronic dimension that unifies the disordered world.

Life, in the view I have been proposing, is a hard-won and constantly maintained moment of structure and stability emerging from a surrounding ocean of directionless activity. It thus

[22] For more detail, see Dupré and Leonelli 2022.

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exemplifies what I take to be a more general truth about the world that, as Heraclitus famously proposed, everything flows. Even if I have failed to persuade the reader of the truth of the Heraclitean thesis, I hope to have demonstrated at least that science and metaphysics are highly relevant to one another.

I end with a confession. While certainly the aim of philosophy should be to say what is true, I suspect most philosophers have reasons for defending positions beyond mere epistemic conviction. My confession is that I like the processual view of reality. The billiard ball world is a deterministic world in which, compatibilist protestations notwithstanding, we are spectators of events in a world whose evolution was decreed inexorably in the distant past. The process world is open-ended. We are, to some degree, architects of our own fate, with the potential not merely to impose order on the chaos, but to impose order of a kind that we choose. Needless to say, we often do this badly. But the metaphysical possibility of doing better seems to me an essential ingredient for the hope that we may learn to do so.

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