Patterns All The Way Up: Prolegomena to a Future Naturalised Metaphysics

James Ladyman, Department of Philosophy, University of Bristol[1]

Dennett's idea of real patterns was intended as a way of vindicating propositional attitude attribution within the scientific image, and it has been extended to understand the relationship between emergent entities and their components more generally. The notion of a real pattern has been applied to understand the ontology of various sciences, and it is central to the project of naturalised metaphysics for science as a whole undertaken in Ladyman and Ross (2007) (hereafter `ETHG'). Dennett's account is developed by David Wallace (2003) as part of a functionalist conception of emergent ontology applied to Everettian worlds. In that context, only higher-order entities are understood in terms of real patterns, whereas the wavefunction is understood in categorical rather than functional terms. On the other hand, Ladyman and Ross eschew the idea of a fundamental level and advocate a real patterns account of ontology across the board (including also merely notional or representational real patterns). Most other applications of the idea of real patterns in philosophy of science involve emergence from something other than fundamental physics. Vanessa Seifert analyses the chemical bond as a real pattern in the charge density of valence electrons (2013). Daniel Burnston (forthcoming) argues that neuroscientific models of decision-making are based on real patterns in the activation profile of the brain. Margarida Hermida (this volume) considers the tree of life as a real pattern in genealogical relationships, Ryan Nefdt (2023) argues that languages are real patterns in the behaviour of some biological systems, and Wallace (this volume) discusses real patterns in physics that are not directly related to fundamental physics.

Dennett did not envisage the uses to which his work has been put in metaphysics, about which he was rightly sceptical, but at least those applying his ideas have shared his naturalism. He focused on the philosophy of cognitive science which he thought about in Darwinian terms, and so he addressed the primary question of naturalised metaphysics, namely, how does science as a whole hang together? A central secondary question is, how do the ontologies of the different sciences relate, and, in particular, what is the place of physics within science as a whole? Dennett's teacher Quine argued that to be is to be the value of a bound variable, developing the idea that the criterion of existence is being quantified over in our best overall scientific theory, which he imagined as rendered in a purely extensional language, eliminating quantification over the objects of the special sciences in favour of physical objects and sets of them (1948) – the scientific image as desert landscape. This position amounts to antirealism about almost all of the ontology of science, including the ontology of physics, most of which deals with non-fundamental entities. Furthermore, (as discussed below) the most fundamental current physics that is well-confirmed and accepted is agreed to be incomplete, making for a blank scientific image with 'watch this space' written on it. On the other hand, it is not possible to apply Quine's view ecumenically to scientific theories other than fundamental physics, because the objects of the special sciences are not all in a single domain. For example, a solid object like an iron bar can be modelled in continuum mechanics, but also with the atomic-lattice model of particles and bonds in which matter is not continuous. More generally the energy and timescales of the entities can be incompatible, so for example, there is no ordinary matter at very high temperatures only

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plasma, or they are at different levels of abstraction as with individual organisms and species. Science cannot be thought of as conjoined into a single theory with a single domain.[2] Dennett's idea of real patterns can be taken as an alternative to Quine's criterion of ontological commitment: to be is to be a real pattern, where a real pattern is something that indispensibly figures in projectible generalisations that predict and explain the behaviour of the world. The sciences (and common sense) posit such objects, properties, relations and processes that allow the formulation of such projections. Dennett's real patterns are computational. The compression of data and the reduction of information processing is made possible by a high-level description of a system that could in principle be described at a fine-grained level, but at a much greater computational cost. In Conway's Game of Life – Dennett's central example – the emergent objects – gliders, eaters – are mereologically composed of a small number of illuminated cells, and successive instances are composed of different cells, and successive instances a few steps apart have no cells in common. They persist only structurally.

The idea of real patterns exemplified by the Game of Life has several important positive heuristics for naturalised metaphysics.[3] First, the idea of emergent patterns is generally applicable to how science represents the world. The days in which it was widely supposed that scientific theories could be rendered in first-order logic are long gone. On the alternative model-theoretic or semantic view of theories, scientific representation is to be understood as more analogous to a map than a set of sentences in a formal language, and mathematical representation is considered to be ineliminable. Scientific theories are very diverse, but all their ontologies are based on concepts that amalgamate mathematical and concrete concepts to describe emergent structure. The decision trees of evolutionary game theory are representations of a structure that only comes into being when there are populations of individuals whose choices and preferences approximate those of a particular game. Strategies and equilibria among them are aptly thought of as emergent real patterns. In chemistry the example of the chemical bond noted above can be augmented by the Periodic Table, which can be represented pictorially in different ways, and has no exact form since a few of the elements can be put in more than one place depending on which aspects of their chemistry are to the fore (Scerri 2019). The periodic occurrence of chemical properties expressed in the Octet rule that preceded the Periodic Table is very aptly described as a real pattern. Such examples of emergent structure abound across the sciences. The wide applicability of the idea of a real pattern is in part due to its vagueness, but in particular contexts the idea can be made more precise in all the different ways that mathematical science has to describe patterns.

The second positive heuristic is that in general scientific representations often simplify the description of the phenomena. For example, the complexity of the positions at different times of the planets on the celestial sphere is reduced to Kepler's three laws of motion. Science is replete with relatively simple laws and principles. Of course, there is nothing simple about simplicity as much discussed in the philosophy of science, and in metaphysics, but nonetheless in science models and theories do often involve a compressed description of the data one way or another. Thirdly, the idea of real patterns implicitly involves scale-relativity, because the ontology of gliders and eaters is only applicable when more than a few cells over a few iterations is

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[2] Hence some naturalistic philosophers such as John Dupre (1995) embrace pluralism and the idea of multiple incompatible scientific images. On the other hand, below it is argued that the unity of science and the special place of physics within it must be acknowledged.

[3] The terminology of positive, negative and neutral heuristics roughly corresponds to that of positive, negative and neutral analogies due to Keynes (1921) and Hesse (1966). ETMG argues that the task of naturalised metaphysics is to unify physics and the special sciences. It constructs a positive metaphysics based on ontic structural realism in the philosophy of physics, and rainforest realism about the special sciences using the idea of real patterns.

considered (different senses of scale-relativity and their significance for ontology are discussed below).

The analogue of the bit-map in the Game of Life is a description in terms of more basic ontology, and the gliders and eaters are analogous to higher-level ontology. For example, consider the ideal gas laws. Their ontology is that of gases somehow confined to a volume with their properties of pressure and temperature. The laws track real patterns in the behaviour of gases regardless of how they are composed, hence they are multiply realisable.[4] The bitmap is the particles, and the gliders and eaters are the emergent properties of a gas. One real pattern is represented by Boyle's law, which states that the pressure is inversely proportional to the volume at fixed temperature. However, note that the law only fits the data approximately, and only when the volume is changed slowly. In general, the ontology of the gas laws is also scale-dependent in the sense that if there are only a few particles in a vast volume, there is nothing like an ideal gas, but there are still the particles and the laws they obey. The kinetic theory of gases offers a description of the behaviour of the gas when the ideal gas laws break down. Furthermore, particle collisions are described by quantum theory as plane waves scattering off each other, and the particles in question, being atoms or molecules are themselves composite entities.

In general, basing the idea of real patterns on emergence in the Game of Life has several negative heuristics for naturalised metaphysics as well.[5] Perhaps most importantly, the real mechanism that makes the system work is hidden in the implementation of the computation, the particular form of which is irrelevant. In the computational world there is a privileged fundamental level of description that is the bitmap, and then the emergent level of eaters and gliders. There is a finite number of cells, each of which is either on or off, and macrostates are completely determined by and reducible to microstates. Whether or not the world is fundamentally discrete and finite, the way in which the emergent entities are composed of the cells is not analogous to how parts compose wholes in science, in so far as the cells do not genuinely interact, and their interactions do not compose the emergent entities which are themselves not genuinely causal. The gilders and eaters are analogous to life in only persisting structurally, but not otherwise, because real biological systems have to exploit physical and chemical mechanisms to survive. It is a one-dimensional model of reality in the sense that there is no independent way of identifying the real patterns other than in that particular kind of data. In real science objects triangulate data from different sources. Moreover, in real science there are cross-cutting classifications, and multiple domains and scales. For example, temperature manifests itself in numerous other contexts, unlike eaters and gliders.

There are many such lessons to be learned from current science. Some of the following propositions are more or less implicit in prior work by Ladyman and Ross and others, and many of them might seem obvious, but they are worth making explicit and compiling so that naturalised metaphysics can triangulate with them.

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[4] There are two kinds of universality to the behaviour of gases. First, each equilibrium macrostate is associated with numerous microstates, and secondly the same laws are obeyed by gases composed of different molecules or atoms, for example, hydrogen and helium, or a mixture like atmospheric air.

[5] ETMG chapter 4 points out that the Game of Life is misleading as an exemplar of real patterns in some crucial respects. While the account of real patterns in Dennett, Ross (2000) and ETMG is articulated in information theoretic terms, it can also be developed in terms of the dynamics of phase spaces, as Jenann Ismael suggests, and Ladyman and Ross (2013) and Alexseev et al (this volume) argue that another way to understand it is in terms of statistical structures.

(1) The progress of science has involved both the expansion of ontology qualitatively and quantitatively in various domains and at various scales, and the integration of the models and theories of those domains and scales.

Many disputes in the history of science were resolved by expansions of ontology and scale. First Copernicanism required the universe to be much bigger than expected, and then following the `great debate' in the 1920s the existence of galaxies (`island universes') other than the Milky Way was accepted (and it now seems likely there is much more dark matter than ordinary matter). In chemistry the number of elements is over ninety, not four or five, and the number of possible compounds is truly vast. In biology the discovery of microbes was followed by the realisation that not only do they constitute most of the biome by mass, but there is an entirely new taxon of Archaea. Overall, there are vastly more entities and types of entity in current science than in the past, all based on the same core ontology of the elements of the Periodic Table, plus the fields and forces of physics, and the standard physical quantities and units. As well as more individual things and types of thing, there are also many more properties, processes and relations. Properties such as fitness, processes such as adaptation, and relations such as being conspecific, are peculiar to biology, and quite different from those in chemistry such as solubility, oxidation and isomerism. On the other hand, all these entities are understood in an interconnected way, so that the chemical entities mentioned are all relevant to biological systems. Accordingly, there are many boundary disciplines such as biochemistry and geophysics. Even critics of reductionism such as Nancy Cartwright (1999) and Sandra Mitchell (2003) emphasise that science is integrated. Astronomy, biology, chemistry, geology, and medicine were once separate subjects but now they are deeply interconnected.

(2) Ontological commitment in science depends on triangulation across different modalities of measurement, and across different scales and domains.

There are two related ideas of triangulation. The first is the epistemological idea that scientific theories should be supported by multiple independent lines of evidence, which has been central to thinking about the scientific method since at least the writings of Robert Boyle. The second is the ontological idea that a real object manifests itself in more than one way, which is true of everyday objects, and also the objects of science (Hacking 1983). In the best epistemic case, the multiple lines of evidence include multiple kinds of evidence in different domains, for example, many different terrestrial and extraterrestrial data confirmed Newton's laws of motion and gravitational force law, and this remains a prime example of what Whewell called 'the consilience of induction' (Laudan 1971). There can be multiple independent kinds of evidence for an object that manifests itself in more than one way. The atomic theory of matter was universally adopted only when it triangulated in chemistry and physics in many domains and at many different scales (Chalmers 2009), multiple independent precise determinations of Avagadro's number being decisive for some holdouts such as Poincaré: "The brilliant determinations of the number of atoms computed by Mr. Perrin have completed the triumph of atomism. What makes it all the more convincing are the multiple correspondences between results obtained by totally different processes." (1963 [1913], p. 90). Similarly, tectonic plates were originally proposed to explain large length and time scale geological and paleontological data, but they were eventually accepted in the light of data about the current structure of magnetic field lines on the bottom of the oceans (Frankel 2009). Cosmic rays were identified as charged particles not photons because their intensity was found to be affected by the magnetic field of the Earth (Hartog 1949). The ontological commitments of the sciences in general, such as cells, galaxies, hurricanes, molecules, people, and social structures are epistemically on a par with those of physical science in so far as they triangulate across different modalities of measurement, and different scales and domains too. Triangulation in this sense is very similar to Ruth Millikan's idea of `clusters' which she understands as non-accidental (2017, p.13).

(3) The diversity of the ontology of science is paralleled by the diversity of the kinds of causation, equilibria, laws, mechanisms, powers, probabilities, principles and symmetries in science.

Aristotle's four kinds of explanation have given way to a multitude. The varieties of scientific explanations now include the explanation of the adaptation of the eye by natural selection, the explanation of the geopolitics of the cold war in terms of the Nash equilibrium of mutual assured destruction, the explanation of the abundance of iron in the universe by the stability of its nucleus, the explanation of the falling of a cat by the law of conservation of angular momentum, the explanation of the firing of nerve cells in terms of action potentials, the explanation of acidity in terms of valence electrons, the explanation of the stability of matter by the Pauli exclusion principle, and the probabilistic explanation of dosimetric data provided by nuclear physics. Causal explanations alone defy the many ingenious attempts at unitary analysis, so causation is plausibly of various kinds, both in respect of causal concepts, and their targets in the world (Cartwright 2004, Godfrey-Smith 2010). All the other kinds of modality mentioned above are discussed in the metaphysics of science literature, and the idea that they can all be reduced to one kind is even more implausible. On the other hand, there is no naturalistic motivation for eliminating modality from science altogether (whether by understanding all explanations as subsuming particular facts under regularities, or as fictions), because all scientific ontological commitments are based on the identification of something in a local environment relative to which it has some kind of stable modal profile. Successful scientific representations are projectible, supporting explanation, prediction and counterfactual inference, and there are no real things without projectibility, so an ecumenical attitude to the modalities of science as well as its ontology is appropriate. Indeed, the two go together since, on the real patterns understanding of emergence, objects and their modal profiles are inseparable, just as, for example, electrons are inseparable from Pauli's Exclusion Principle and the laws of quantum electrodynamics. The blurring of the distinction between objects and modal structure is well exemplified by stars, because they are understood as individual objects *by* being understood as processes, and by galaxies, which maintain a steady state over billions of years by stars being born and dying constantly within them. Similarly, macroscopic objects are understood as relatively stable and enduring real patterns that emerge from the myriad interactions of their component atoms and electrons.

(4) The concept of natural modal structure is an abstraction which includes all of the above. In formal mode this modal structure is absolute, but in material mode it is domain and scale-dependent.

Modal structure is the genus to which the different species of causal structure, nomological structure and so on belong, and all may also be thought of as kinds of real pattern. They are not to be thought of as mere regularities because the best scientific explanations have in common that they are associated with reliable predictions and counterfactuals. For example, Newton's law of gravitation made numerous predictions and tells us that the Earth's orbit would be less stable without the Moon. A general form of realism about science is expressed by the commitment to the reality of the modal structure tracked by our best scientific theories. [6] Novel predictive

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[6] ETMG argues on the basis of consilience that natural modal structure is represented by science, and defines real patterns modally. Probability and statistics, and computation and information are all modal and all ubiquitous in science. Realism about modal structure is a core commitment of Ontic Structural Realism (Ladyman 1998).

success, such as the detection of the Higgs Boson and gravitational waves, has long been regarded as the strongest possible form of confirmation, and yet none of the most predictively successful theories to date are universally true in all domains at all scales. When we attribute modal structure with a scientific model (in formal mode), we represent it as obtaining indefinitely in space and time, ignoring many aspects of systems and their environments (in material mode). Consider the model of the harmonic motion of a pendulum. Real pendula only ever behave like that over some time period, in respect of some of their degrees of freedom, and only approximately. Furthermore, any causal or lawlike structure is attributable to a real system only in so far as it and its local environment are not subject to a significant perturbation. Every attribution of modal structure to systems on the earth is modulo the non-occurrence of an imminent asteroid strike, and all other modal structures break down at very high temperatures and in the very early universe, as well as in exotic astrophysical conditions such as within neutron stars. No real system obeys time-translation invariance if the transformation is big enough because it has a finite past, not just because the materials from which it is made are produced in complex processes, but because elements more complex than hydrogen and helium only exist in abundance after more than one generation of stars. Correspondingly, every physical system on Earth has a finite future if only because the Sun will eventually die.[7]

(5) There is modal structure to the way that domains and scales relate.

There are connections between domains and scales that are not accidental and arbitrary, but projectible and systematic. Correspondingly, when the modal structure represented by a theory breaks down this can often be described and modelled in terms of another theory. For example, the laws of ray optics are approximately true for the behaviour of light when its wavelength is small relative to the things with which it is interacting. The relations between the domains and scales of ray optics and wave optics are structured by the nature of light, and the more fundamental laws hold when the less fundamental ones do not, for example, when there is diffraction, or when the light is considered in conditions in which it behaves like photons and not like a classical wave. Sometimes the connections take the form of law-like relations, and, in general, in physics theories about different domains are often related by mathematical limits, as with special relativistic and classical mechanics. There is also modal structure to the relations between domains and scales in the form of affordances and constraints. For example, the modal structure of the relations between physics and biology, such as the biological affordances of the large surface area to volume ratio of a wing, and the constraints of a large mass on the shape of wings in birds compared to insects (Hermida and Ladyman forthcoming). The affordances and constraints governing reactions among chemical substances reflect the modal structure of the electromagnetic force between charged particles, the electronic shell structure of atoms, and the spatial structure of molecules. Science includes theories that link the levels, but in almost all cases the higher-level description is spatially and temporally coarse-grained, approximate and aggregative with respect to the underlying description, so reduction based on type-type or token-token identity relations between higher-level and lower-level entities is not plausible. For example, the pressure of a gas is an average property of a volume of gas over some short time, and it moves pistons which a set of instantaneous microstates cannot do, so the macroscopic property of pressure is not identical with any of the specific microstates associated with it in statistical mechanics nor with any property or set of them.[8]

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[7] Physics studies particular objects as well as generalising, and so physics is also partly an historical science. This has always been true of parts of solar system physics and geophysics, but now the actual history of the whole universe is modelled in general relativistic cosmology.

[8] ETMG argues against ontological reduction understood as requiring either type-type or token-token identity. There are various accounts of reduction in current philosophy of physics that do not require either. Clearly

(6) Sometimes the modal structure of the relationships between domains and scales is due to composition or part-whole relations, but these relations are in general diachronic, dynamical and involve domain-specific interactions and relations among parts.

Richard Feynman (1963) said that the single most informative proposition in science is that everything is made of atoms. This is apt to mislead because in current metaphysics composition is usually understood in terms of mereology which considers part-whole relations in general. It tells us that parthood is antisymmetric and transitive, and there are various interesting formal systems with further features. However, it does not treat of interactions and other relations, whereas scientific accounts of composition almost always involve them. In the case of the atomic-molecular theory of matter, the behaviour of gases and liquids obviously depends on the dynamics of their parts, but even the seemingly fixed structure of solids is due to their electromagnetic interactions. Furthermore, ultimately the electrons and nuclei that compose them are dynamical entities, and so atoms are not simple mereologically or otherwise. Proteins only have their functional properties because of both the sequence of their component amino acids and their shape. The immune system has its functional properties due to its component entities and the signals they send to each other. Organisms compose an ecosystem because they interact, likewise for cells and multicellular organisms. This introduces various forms of scale-dependence. Most composite systems with emergent features have large numbers of parts that interact many times. Anderson's (1972) `more is different' in condensed matter physics refers not only to particles but also to their interactions. In complex systems in general, order and self-organisation can emerge spontaneously from the repeated interactions among parts. There is often a very large separation of timescales associated with emergence. For example, the interactions of the atoms or molecules in a gas take place on a very short timescale compared to the timescales over which macroscopic properties are operationally meaningful. Despite rhetoric about emergent phenomena defying reductive explanation, complexity science involves breaking things into parts and studying their interactions to understand the behaviour of the whole. Order and organisation can arise even in simple non-living systems when they are driven exogenously in some way, so that the effect of the environment on them cannot be ignored (Ladyman and Weisner 2020).

(7) The modal structure of the relationships between domains and scales can be construed in terms of dependence, determination, or supervenience.

For example, the laws of stellar evolution depend on the laws of nuclear physics, the hardness of diamond is determined by its tetrahedral unstrained bonds, and the software states of a computer supervene on the states of those of its physical degrees of freedom that are implementing the computation. In discussing the relationships between different domains and scales in science terms such as 'based on', `gives rise to', and `fundamental' are also used. While philosophers often seek to regiment such terminology purely linguistically, scientists do so with mathematics, models and theories.

(8) Physics is the science that covers the widest range of scales and regions of space and time.

Biology only applies where and when there is life, and the social sciences only where there are collections of people interacting. Chemistry only applies at energies at which nuclei can capture electrons in their outermost shell (valence electrons), so there is no chemistry at very high

naturalistic metaphysics must acknowledge the success of reductive projects in science of which there are many as noted above.

temperatures. According to the standard model of cosmology, in the very early universe there was no matter other than hydrogen and helium gas and before that there were not even protons and neutrons. Later when black holes have formed there are regions of very high curvature that are also incompatible with the existence of ordinary matter. Electromagnetism applies to molecules and to pulsars, and from the shortest to the longest length scales, but it breaks down at the energy when it becomes unified with the weak interaction. Hence, although a lot of physics applies with very great generality, ultimately all of physical science is scale-dependent or domain-specific to some extent. Arguably the most generally applicable part of physics is thermodynamics, which is critical for chemistry, biology and all of physical science.
(9) The modal structure of the relations between domains and scales reflects the fact that materialism has been successful as a research programme in science.

The programmes that created new physical ontology and processes exclusively to account for chemical, living and cognitive systems have not had any scientific success, while programmes based on understanding such systems in terms of more fundamental physical ontology and processes have been successful. The modal structures of the different sciences all stand in modal relations with the modal structures of physics directly, as in biophysics, and indirectly as in the relation of endocrinology to biochemistry to physics. Among the most successful reductive programmes is that of chemistry to physics in so far as chemical properties can now be predicted by the application of electromagnetism and quantum mechanics to molecules. In biology the functional profile of proteins is based on the amino acids they contain and their shape, which determines how they interact with other molecules. Furthermore, physical features of systems, and physical measurements are central to the rest of science. This is why ETMG demarcated naturalized metaphysics with the Principle of Naturalistic Closure (PNC):

"If a metaphysical claim is to be taken seriously at a time *t*, it should, if true, show how two or more *scientific hypotheses*, at least one of them *specific* and at least one of them both specific and drawn from fundamental physics taken seriously at *t*, jointly explain more than the sum of what is explained by the two hypotheses taken separately. (Ladyman and Ross 2007, p. 37)"

However, this is problematic because it makes reference to fundamental physics. It might be modified to refer instead to `a more fundamental theory', where that will often be a theory from physical science.

(10) The physics that is fundamental with respect to the special sciences, and which unifies them, is not absolutely fundamental, and there is no single fundamental physics.

The elements of the Periodic Table and the four fundamental forces of nature are not all ultimately elementary. Furthermore, in the current scientific image there is not a single privileged level of description, because there is no single fundamental physics, rather there is the Standard Model and General Relativity. Dark energy and dark matter, as well as quantum gravity are largely mysterious.

(11) There is no single hierarchy of levels, nor are there sharp boundaries between domains and scales. It should also not be assumed that there is a single fundamental level.

Accounts of reduction and emergence divide the world into levels, and while there is structure at many scales, there is not all kinds of structure at all scales. However, ideas of levels of ontology should not be understood as corresponding to distinct global levels of existence. There is no single hierarchy because there are various different kinds of relationship between lower-level and higher-level entities. Sometimes different levels correspond to distinct but related properties, for example, the conductivity of a metal, and the dissociability of its electrons. Levels may also be associated with different length scales, but need not be, for example, the different levels of description in micro and macro-economics. Sometimes different levels correspond to a part-whole relation as with the levels of cells and organisms, but of course some organisms are unicellular. It may also be useful to divide the world into the living and the non-living. In specific models and theories there may be also be a distinction between levels, as for example, the levels of microstates and macrostates in statistical mechanics. The idealisation of separate levels often depends on the effective separation of the timescales of the relevant dynamics, for example, in the separation of the electronic and nuclear dynamics due to their vastly different masses, and the separation of the dynamics of the interactions of the cells in a muscle fibre from the dynamics of a running animal.

The idea of a single hierarchy starting with subatomic physics, and going up through chemistry to biology and psychology does not correspond to anything in scientific practice. Theories and models in science often cut across scales to some extent, and as noted in (2) above ontological commitment in science usually requires that entities in question triangulate different evidence from different domains and at different scales. Physics ranges from the scale of quarks and leptons, to that of superclusters of galaxies, but high-energy physics is applied to understand both the minutiae of collisions in particle accelerators and to the life-cycle of stars. In physics the low-energy is often the emergent, and the higher-energy the more fundamental, and this also often coincides with bigger and smaller respectively, and with the whole-part relation. However, they come apart in some contexts including when it comes to the most fundamental physics, as higher-energy corresponds to smaller length scale in particle physics, but not in gravitational physics. In quantum mechanics more fundamental does not mean smaller because of entanglement. The levels of ray optics, wave optics, electromagnetism and quantum electrodynamics do not correspond to the levels of sub-atomic, atomic and molecular. Molecules can be microscopic, mesoscopic and macroscopic. Even within physical science there is no single hierarchy of fundamentality, and hence no determinate notion of the ultimate fundamental level.[9] The vast ontology of biology covers scales from the microscopic to the planetary including many functional entities that are not part of the ontology of chemistry and physics, but also including non-living things such as amino acids and carbon dioxide. Iodine is part of the ontology of endocrinology, but so is the thyroid gland. The levels of functional organisation in biology do not correspond to differences in length that are relevant to physics, and in biological systems processes at very different scales are coupled in ways that depend on their histories. The boundary disciplines are necessary because of the multiple and vague interfaces between domains and scales as discussed.

(12) All existing theories have an effective ontology of emergent entities. Effective ontology is scale-dependent.

Sokal and Bricmont (1997) defend what they call the renormalization group view of the world, and Ladyman and Ross claim that in general "[o]ntology is scale relative in respect of both space and time". There are different kinds of scale including lengthscale, timescale, numerosity of parts, and numerosity of interactions, and different domains associated with different degrees of freedom. The idea of scale-relativity and effective ontology is standardly discussed in the context of the quantum field theories of the standard model because they break down at very high energies. However, thinking of the objects of physics in a domain or scale-dependent way goes

[9] ETMG argues that there is not for all we know a fundamental level of reality (though there might be), and that accordingly our metaphysics should not presuppose that there is. Many commentators took the claim that relational structure is fundamental to be a form of fundamentalism (for example, McKenzie 2017), but it was not so intended.

back much further. Arguably, the application of the law of the lever requires that the physical object being used is thought of as a rigid body, whereas in fact it is more or less obviously distorted to some extent by the application of a force. In other words, the law of the lever applies when the body used is effectively rigid when subjected to the forces being applied and not otherwise and so the law is effective. Every object, property or event is classified in a way that does not capture modal structure at all scales, where energy scales are also relevant and correlated with length and timescales in interesting ways. For example, over very long timescales not even the most enduring and natural ordinary objects existed, because in the early universe there was no ordinary matter. Similarly, in the future the Earth will be absorbed by the Sun when it becomes a red giant. Everything in chemistry depends on thermodynamic equilibria and free energy, both of which are dependent on pressure and temperature. The laws of chemical reactivity are therefore all scale-dependent.[10] More fundamentally, the elements and compounds with which chemistry is concerned do not exist at temperatures at which electrons have enough energy to escape being bound by nuclei. The most perfect vacuum ever made in a laboratory on Earth has a higher density of atoms and molecules than gases in astrophysics, so whether or not a region of space is thought of as occupied by a gas is scale-relative, and a matter of whether it is effectively described as such.

If the idea of effective ontology sounds too vague for proper science here is one of the greatest mathematical physicists of all time in his book on classical mechanics: "A body so small that, for the purposes of our investigation, the distances between its different parts may be neglected, is called a material particle" (Maxwell, p.3). This means that a planet may be a particle for some purposes. Maxwell here refers to purposes, but the constraint on what is effective in what context comes from the world. Classical mechanics is completely useless for describing the behaviour of electrons. Vagueness is a consequence of effective ontology because the usefulness of a model often breaks down by degrees. A pendulum subject to significant friction may not look very harmonic for very long. The number of tectonic plates depends on exactly how they are defined, as does the number of layers of the atmosphere and where exactly they start and stop. However, vagueness is not complete indeterminacy, and everybody agrees about the major tectonic plates and the major atmospheric layers, though seeking to define either to within a millimetre would display complete ignorance about the relevant domain and the characteristic scale of its features. Accepting the idea of effective ontology helps reconcile scientific realism with theory-change, and also to some extent with common sense realism in so far as many everyday objects, most obviously material objects like tables have at least some of their properties as effective scientific entities in the scientific image.[11] Effective realism reconciles the scientific descriptions of different domains and scales. There are real patterns in the world that are only discoverable at the right scales of resolution and degrees of approximation. Not recognising them is missing something about reality, and that is enough to say that the objects, properties and processes described by the special sciences are real.[12]

(13) Downward causation understood as the intervening of the higher level in the lower level directly is not coherent, because there are no distinct levels, and because the higher-level entity acts via its parts.

Scientific images founded on a fundamental physical level seem to leave no room for causation in the rest of science. Naturalistic philosophers often embrace ideas of downwards causation in order to vindicate the genuine causal power of entities in the special sciences, and hence the

[10] For other examples of scale-relativity in chemistry see Hendry (2021) and Ladyman and Seifert (forthcoming).
[11] See Ladyman (2018), and Ladyman and Lorenzetti (forthcoming).
[12] The term 'special sciences' is usually used to refer to everything other than physics, but for the purposes of naturalised metaphysics most of physics is a special science because it deals with effective emergent entities.

genuine reality of the emergent entities of the special sciences (emergence without causation being considered merely epistemic). However, the difference making causes that are sought in the special sciences are often at the higher-level because the difference in question is to an explanans that refers to higher-level facts. The relevant difference-making cause of the increase of the pressure of a gas is the increase in temperature even though any change in temperature is associated with a change in the microstate. In the special sciences one is usually interested in 'universal' forms of behaviour, where 'universal' means independent of the detailed behaviour of microphysical or other kinds of constitutive states. The identification of universality and the appropriate descriptive categories for tracking it is one of the principal tasks of the special sciences.

(14) In science it is sufficient, and usually necessary, to track only the statistical properties of low-level entities when tracking high-level entities. Special science ontology involves abstraction, aggregation, approximation and coarse-graining.

The special sciences are possible in so far as the data in a given domain are to some extent algorithmically compressible. The models and theories of the special sciences track the emergent collective behaviour of systems using fewer degrees of freedom than would be needed to describe the underlying state of the system (Wilson 2010). For example, in condensed matter physics, the renormalization group describes transformations that allow the number of degrees of freedom in the Hamiltonian of a system to be massively reduced while still recovering the critical behaviour of the system. The reduction in the number of parameters needed effectively to describe systems is exactly what the theory of real patterns aims to capture. However, scientific real patterns are lossy in the sense that the compression of the information allows only approximate or probabilistic recovery of the behaviour of the underlying system (unlike the real patterns in the Game of Life). It is possible to use much less information to predict the behaviour of systems described in an approximate and probabilistic way, than would be needed to describe everything about them. Emergence in physics is often described in terms of `coarse graining' with respect to underlying degrees of freedom. The ideal gas laws use only three degrees of freedom to give a pretty good description of the behaviour of systems that have of the order of 10^{23} degrees of freedom. Hence, changes in pressure or temperature are difference-making causes with respect to the coarse-grained ontology. This is another reason why even token identity does not obtain. If one ignores emergent real patterns one misses out on a real feature of the world.

(15) The idea of a description of the whole universe at all scales has nothing to do with any scientific theory that we could develop, test and use.

Any actual scientific theory can only be about part of the universe in some respects at some scales, because it is used by agents that cannot include a complete description of themselves in the model (this is why the definition of real patterns in ETMG refers to perspectives). It is also necessary that the agents have information channels to the system and its environment, and internal states with which they can compute. The agents assume that their effects of the rest of the universe can be ignored, and that the rest of the universe can be separated into a system and its local environment. It is also often, but not always assumed that the effect of the system on the environment can be ignored, as with the notion of a heat bath which is considered so large compared to the system that any heat flow to or from the system to it does not change its temperature. It is also often but not always assumed that the effect of the environment on the system can be ignored, so that the system can be modelled as if it was the only thing there is.

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