WHERE SCIENCE MEETS MIND: On the Concept of Emergence in Physical and Mental Realms

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Abstract

Emergence in physical reality involves the mental act of an agent, the scientist. It is the inverse of the operation of reduction. Physical emergence is compared to the mental emergence of phenomenality,[1] which also involves operations of an agent, the brain. In both cases, the scientist (philosopher, observer, etc.) initiates the notion of emergence by first positing a more fundamental level. Both cases reflect the epistemic relationship of subject to object—of mental to physical—and both entrain problematic circularity.

1. Introduction

Emergence is said to occur when an entity is observed to have properties its parts do not possess.[2] It is often associated with complexity, self-organization, and development over time. The focus is often on something presupposed to be independent of observers. Emergence then seems to be an ontic phenomenon rather than epistemic. In physics especially, emergence is deemed the result of physical processes, if not a physical process itself. From that point of view, the laws of physics and even the cosmos itself are emergent, for which some sequence of causal processes is sought but also presumed.[3]

For there to be parts there must be a whole to begin with. The reductive analysis into parts is a mental procedure, a prerequisite to the appearance of emergence. Emergence can be regarded as a reciprocal sequence of mental operations—an epistemic or even psychological procedure. While the world is considered an objective presence, independent of observers, thinking about it is a human activity conducted by observers: the concept of emergence inextricably involves the subject as well as the object. If emergence appears to be a feature of the physical world, it is first a feature of scientific description.

As most scientists would agree, not only do the complicated *behaviors* of the human organism arise somehow through the activities of neurons; but, also the very *appearance* of the world to us, with its qualia as well as properties, arises somehow through neural activity. Both phenomenality and physical phenomena arise in the mind of a subject, through cognitive or mental operations.[4] What will be explored here is the relationship between the emergence of phenomenality from brain activity and the emergence of physical properties at one scale from those at another. These will be explored as dual aspects of the same thing. In particular, as a mental operation, emergence will be viewed as the reciprocal of the mental operation of reduction.

Macroscopic properties of a gas—pressure and temperature, for example—are said to emerge from the kinetic energies of molecules. Before they were formalized as parameters measurable by instruments, however, pressure and temperature were first sensations "measurable" by sense organs. Temperature and pressure existed on the ordinary human scale before being conceptually *reduced*

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[1] 'Phenomenality' is commonly defined as "the state or property of being phenomenal." However, 'state' and 'property' are already derivative abstractions, whereas 'phenomenality' will here be used to refer directly to the range and the actual occurrence to a subject of all "appearances" that the subject can experience: sensations, emotions, thoughts, etc.

[2] Wikipedia: Emergence

[3] "Most of the laws of physics themselves as we experience them today appear to have emerged during the course of time making emergence the most fundamental principle in the universe and raising the question of what might be the most fundamental law of physics from which all others emerged." [Wikipedia, ibid] Through cosmic inflation after the Big Bang, the current universe is thought to have emerged from a quantum fluctuation!

[4] Of course, they also both depend on objective external events.

to effects of the kinetic theory and events at the microscopic scale. Experience on the ordinary human scale was the departing point for inquiry that led to a search for a more "fundamental" level of reality from which to explain and derive ordinary appearances. Emergence *presupposes* reduction; for, without a prior reduction, there is nothing to emerge *from*. Without reductive explanation, one simply remains where one begins, on the default level of ordinary experience. Moreover, since subject and object are inextricably entangled, we cannot speak of emergence as a *physical* process without invoking a corresponding *mental* process.[5]

The notion of "new" properties emerging—for example at one scale from another—bears this dual understanding of novelty being a function of physical time-evolution and of being a *discovery* by an epistemic agent. In terms of the latter, an intentional *operation* (such as reduction) performed by an agent ought to have a definable inverse. In terms of time-evolution of physical reality, however, there is no guarantee that strict determinism holds, such that the present observed universe could be reconstructed from fundamental laws and past initial conditions. Rather, determinism must be interpreted in an epistemic rather than ontic sense: an agent is able (or not) to determine a relationship between events. Laws are deterministic only in the sense that equations are mental constructs defining reversible operations. The equations, not reality, are deterministic and time-reversible.

Can emergence be objectively quantified and measured? A recent paper proposes to do so with the aim of discovering emergent processes that do not "leap out" at the cognitive capacities of human observers.[6] Some emergent patterns strike us as obvious, such as the flocking behavior of birds or the aggregation of stars into spiral galaxies. Such phenomena stand out as cognizable "objects," which (though having a real external basis) are clearly dependent on our cognitive abilities. Others, like patterns of neural firing, do not stand out for us in a way that suggests emergent phenomena: their connection to the organism's macroscopic behavior is not immediately obvious. Might it be possible to discover and predict emergent phenomena beyond our (visual) cognitive abilities? That is, to objectively reveal, through "parametric modeling," subtle patterns that can potentially become emergent to our eyes?[7] Perhaps so, at least in principle; yet such detection is nevertheless a cognitive activity, though in a different mental domain than the visual. In all cases, the task is to connect the emergent level to that from which it emerges—causally, if possible. The perspective of the observer examining the brain to discern patterns of neural discharge is not the same as the brain's own perspective. The connection between levels is not obvious to the observer, who may or may not be able to trace the macroscopic organism's behavior and perception back to its origin in the microscopic activity of neurons. Nevertheless, the *brain itself* establishe*s* the connection, if in reverse: it *produces* the emergent effects which the neuroscientist wishes to formally derive.

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[5] James P. Crutchfield "The Calculi of Emergence: Computation, Dynamics, and Induction" in Physica D (1994) special issue on the Proceedings of the Oji International Seminar *Complex Systems — from Complex Dynamics to Artificial Reality,* 5 - 9 April 1993, sec. 1.2. Crutchfield calls the physical sense of emergence intrinsic and proposes that in "intrinsic" emergence "patterns take on their 'newness' with respect to other structures in the underlying system.' However, he admits that "Defining structure and detecting the emergence of complexity in nature are inherently subjective, though essential, scientific activities… An observer's notion of what is ordered, what is random, and what is complex in its environment depends directly on its computational resources… The discovery of structure in an environment depends… on how those resources are organized."

[6] L. Barnett and A. K. Seth *Dynamical independence: discovering emergent macroscopic processes in complex dynamical systems.* {arXiv:2106.06511v2 [nlin.AO] 6 Aug 2021}: "…we detail how dynamically-independent macroscopic variables may be discovered in state-space systems via numerical optimization…" [sec 1.1] However, the concept of 'dynamical independence', as they define it, seems problematic. They summarize [sec 5]: "while prescribed by the microscopic process, a dynamically-independent macroscopic process is, conditional on its own history, independent of the history of the microscopic process." How can the macro-state be both prescribed and independent?

[7] The authors propose to show in a general way at least how "dynamical dependence [of one level on another] may be computed explicitly for linear systems via state-space modelling, in both time and frequency domains, facilitating discovery of emergent phenomena at all spatiotemporal scales." [ibid, abstract]

Similarly, while flocking or swarming behavior is obvious to our eyes, the causes of it might or might not be discovered in the behavior of individual members of the flock, who nevertheless *do* produce the emergent behavior.

The behavior of stars in the galaxy is derivable from classical laws of dynamics—all on the macro scale. To derive classical dynamics from quantum dynamics remains one of the great theoretical challenges of modern physics; many believe that such a unification is possible and pending. For an account of galaxy formation, there may or may not be something to gain from the integration of gravity with quantum theory: we don't yet know. A humbler example is the challenge to derive, by way of explanation, the macroscopic properties of liquid water from its chemistry. That effort has been remarkably successful; it has been shown how the properties of liquidity, density, viscosity, etc., emerge from chemistry and physics at the molecular level.[8]

Note, however, that *property* is not the same as *quality*, which refers to the phenomenal appearance to a subject, especially via the senses. A quality is a first-person experience; a property is a third-person concept abstracted from experienced qualities. Macroscopic properties (e.g., of water) "emerge" from microscopic properties because the latter have already been discovered through scientific research that establishes a reductive theoretical domain as a basis on which to explain macroscopic properties. Qualities—such as the perceived wetness, taste, and appearance of water—similarly seem (to the scientist) to mysteriously "emerge" in the mind from a theoretical substrate (i.e., nerves) already established by the scientist. In both cases, a reductive domain is created by the observer-scientist, who performs the operation known as reduction. The difference is that, in the one case, the inverse operation called "emergence" is also performed by the scientist; in the other, it is performed by the brain.

2. Subject and object

The human mind seeks always for an essence at the core of things. In the case of science, this consists of a minimal ontology of what fundamentally exists, plus minimal compressed descriptions of the patterns of its behavior, in the form of mathematical "laws." What is sought is a single, unifying and ultimately "reduced" conception from which all appearances can be derived—effectively, a "theory of everything." A plausible psychological motive for such compression is the existential security that attends the ability to predict and control the course of events, on the basis of a unified fundamental model. Such a motive would presumably be favored in natural selection because of its survival value.

Such a program is inherently reductionist, seeking to compress information to a formula. It assumes that physical reality has a bottom level of simplicity that cannot be reduced further, and that the complex appearance of the world to human subjects is somehow reconstructed by the mind from these fundaments. This implies that there must be an inverse to the mental operation of reduction; it must be possible for the scientist, too, to reconstitute the original that we begin with in ordinary experience, since the brain normally does it. The program is also taken to mean that there are physical processes through which phenomena on one scale emerge causally, usually from phenomena on a smaller scale, through an evolution in time: the universe constructs itself from its own fundaments. There thus appear to be two kinds of emergence, one mental (or computational) and one physical (and causal). The goal here will be to explore what they have in common.

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[8] See, for example: Emiliano Brini, Christopher J. Fennell, Marivi Fernandez-Serra, Barbara Hribar-Lee, Miha Lukšič, and Ken A. Dill "How Water's Properties Are Encoded in Its Molecular Structure and Energies" *Chemical Reviews* 2017

In terms of the program of unification, problematically there also seem to be two domains of discussion: one of *appearances* (i.e., phenomenality) presented to the subject and another of events *objectively real* and independent of the subject. It seems (at least to the self-conscious human mind) that all events in the external world, when perceived or imagined, are necessarily also events in the subject's inner realm, where they are represented in ways conditioned by the nature and cognitive needs of the subject as well as by the properties of the object.[9] This joint dependence renders problematic the quest to track objective reality independent of the subject.

The mind committed to objectivity naturally attempts to separate the two influences. This isolation of object from subject is basic to the project we know as science, which in fact attempts to consider the object without regard to any *particular* subject. That is, it filters out the idiosyncrasies of the individual observer in favor of what is common to all observers, by substituting an idealized standard observer and protocol. Observation and thought are not immune, however, from conditions common to *all* observers and thinkers—such as their embodiment as creatures who, for reasons characteristic of the species, conceive an external reality in time and space, with causality and lawful order, etc. Scientific method eliminates idiosyncrasies of the *individual*, but not those of the *species*, nor of the embodied observer in general. Furthermore, the putative domain of the objectively real is, in truth, a domain of *concepts* about the world. These are just as much a joint product of object and subject as is our phenomenality, except that the subject is collective rather than individual.

Kant attempted to show that space and time, for example, are built-in mental templates for phenomenality rather than inherent properties of external reality.[10] Yet, science typically ignores any role these templates play in shaping its vision of reality. At least until recently, it has assumed space and time as fundaments of external reality, rather than fundaments of the human mind. Along with space and time, it has similarly embraced causality, determinism, rational order, etc., as essential aspects of physical reality itself.[11] This is reasonable from a point of view that seeks to consider the object independent of the subject. From a broader perspective, however, by leaving out the subject it ignores basic mental constraints on how the physical is conceived. This "loose end" causes problems in thought outside the strict confines of science, such as the dilemma posed by consciousness (the so-called "hard problem"). The omission must also entrain problems within science itself. These were first seriously encountered in the limitations of classical physics that gave birth to relativity and quantum theory, where the nature of "observation" comes under scrutiny. But they were implicit in such earlier dilemmas as *action-at-a-distance* and the incompatible dual properties of light. Indeed, endemic inconsistencies can be traced back to the debates of the ancients over the vacuum and the plenum, atomism and the continuum, the one and the many, etc. Such controversies about the nature of reality hinge on the mind's natural realist bent, which disregards the active role of the subject.

Using only reason, Kant concluded that it was impossible to "know" the world as it is "in itself"—that is, apart from the knowing subject—a tautology, granted the conjoint nature of all experience. Yet, the world is given to us in perception, if not faultlessly; science attempts to know it in ways that transcend the limitations of sense perception. Thought then substitutes for perception, often

[9] Of course, there may be mental appearances and thoughts that do not seem to have any referent in the external world, but that is another story.

[10] What I call 'phenomenality', 'experience' or 'appearances' (meaning contents of consciousness) Kant calls 'intuition' or 'phenomena'.

[11] The early scientists, many of whom were religious, justified such assumptions on the grounds that Man is made in God's image: to the degree that Man is rational, so must be the God who created the universe. Determinism historically reflects the notion of mechanism, combined with that of fate, which follows from divine omniscience and omnipotence.

using instruments that substitute for sense organs. This does not change the fundamental situation that Kant outlined: that the subject cannot know the object as it is "in itself," divorced from the subject's involvement in the act or process of knowing. Instead, it invites us to understand the nature of that act or process. In that light, one sees science not as fundamentally different from ordinary cognition, but as an extension of it, superior for specific purposes.

Concepts into which our notions of fundamental physical reality seem intuitively resolvable—such as *particle, field, force,* etc.—derive from common experience on the human scale. These are extrapolated to apply to the very large, the very small, the very remote in time or space, as though it were reasonable to assume they apply on scales far outside ordinary experience. The latter is what is given to us by our natural faculties, which science deems inadequate to account for the true nature of things. The real question, however, is not what a truer vision would look like (as though putting on corrective lenses), but what it means for knowledge to be "true" and how any form of cognition (including science) relates to that. Kant's point is that there is no way to dispense with lenses of some sort—no unmediated access to the "world-in-itself." The challenge is to understand what "lenses" do for us, whether perceptual or conceptual.

3. The nature of cognition

To get a sense of this challenge, consider again the situation of the brain, isolated in the skull. We might liken it to the hypothetical situation of a mariner confined from birth to a submarine without exit, porthole, or periscope (though it will be equipped with sonar.) This mariner has never had direct experience of the world outside the hull, above or below surface—no prior knowledge of an "external" world or of the workings of "submarines"—but only access to instrument and control panels, connected to what turn out to be remote sensors and activators. The challenge is to discover what these do, and how instrument readings relate to lever settings. There is no reason to suppose that the world outside is anything like the familiar interior of the submarine. Indeed, the challenge is to discover first that there *is* a world outside the hull, and then its properties—what it is like. At the same time, and as part of the same process, the mariner discovers the capabilities of the submarine and how to control it. The model thus formed of the world outside the hull is constructed through interaction with that putative world, essentially by trial and error. Its *truth* means only that it potentially enables the mariner to successfully navigate that realm, just as the very meaning of the *realness* of that realm lies in its ability to affect the navigator. (The world is "real" because the body's interactions with its environment matter crucially to its survival.) "Knowledge" of that world consist in what facilitates (or at least allows) the continuing existence of the submarine.

There are two obvious problems with this metaphor. The first is that we are describing the situation from a narrator's point of view that is impossible for the mariner. It is, in fact, the very picture of the situation—which we present as a *fait accompli*—that the mariner must accomplish from scratch! The second is that there *is* no mariner inside the skull. Or, rather, *the brain* is that mariner; yet, for the brain there is no "inside" environment. It cannot move about as the mariner can within the submarine, has no eyes to see instrument panels nor hands to activate levers. The brain eventually pieces together a model of the world outside. But that is not an extension of a reality found inside the skull, because sensors are largely absent from the brain itself, and are naturally oriented toward the external world. "Reality" (and even the notion of inside and outside) emerges through the model, which comes eventually to include the existence of the brain itself.

The metaphor fails in a third way, since submarines are not living creatures that have come to be what they are through a process of adaptation and natural selection. Yet, both through learning and natural selection, we come to see the world as we need to in order to live. As naturalists, we readily enough admit this biological grounding of sensory cognition in natural selection; yet, we may be reluctant to admit the biological grounding of *science* as a mode of cognition. However well science has augmented natural cognitive capabilities through concepts, theories and instruments, it remains in the same epistemic situation as the brain in the skull.

4. The problem of cognitive domains

A consequence of the above is that science is no freer from explanatory circularities than is natural cognition. The difference, perhaps, is that only in the scientific era has the problem been glimpsed at all. Protagoras and Xenophanes hinted at it.[12] Plato shied away from it in the metaphor of the Cave, choosing to believe that reason could reveal the objective basis of appearances. Descartes recognized that perception, dependent on the nervous system, could be faked; yet he stopped short of the full skeptical implication, claiming faith in reason and the additional rationale that God would not permit systematic deception. Indeed, human beings continue to cling to reason as a better foothold on reality than sensory perception, partly because of the success of mathematics in usefully describing the world. Perhaps Kant was the first to fully confront the problem directly, by recognizing (through reason) that not even reason could fully overcome the epistemic isolation of the cognizing subject.

We need not, like Kant, restrict ourselves to "pure reason" to understand the epistemic situation of the subject in relation to the object. We know that the brain is the principal organ of cognition, which is hermetically sealed within a case of bone. The eyes are not portals (nor even CCT cameras), but remote sensors, whose incoming data stream must be organized and interpreted in order to constitute an image at all. This "image" is a product of "computation" or "information-processing," at least according to current metaphors. Yet, here we see an immediate problem: the brain has formed an image (mental when not visual) of the various elements that supposedly constitute the input to this computation. But that image is in fact the *output* of the computation, recycled as its own input! I call this circularity the "problem of cognitive domains," because the constructed cognitive domain is presumed as its own cause. Lest it be thought that this paradox is a dilemma in psychology alone, consider that the time scale of the very early universe is measured in units of time without meaning before the appearance of cyclical processes some "time" later when electrons were bound in atoms, let alone before the existence of observers to do the measuring.

The problem of cognitive domains (PCD) is that we can only conceive the territory as it is portrayed in our map; circularly, and with no other recourse, we then take the map to *be* the territory. (In Kant's terms, phenomena are mistaken for noumena, by which to explain the emergence of phenomena.) Mental output of the brain is recycled as its own (physical) input.[13] The explanation bites its own tail. This circularity is unavoidable, given our fundamental epistemic situation. It can lead to pointless questions about the relationship between scientific *representation* and the "true" nature it represents. Yet, *understanding* that situation—and avoiding its traps—is possible if we focus on the biological basis and utility of knowledge instead of objective reality.

In its broadest outline, the PCD concerns the relation of mind to world. Basic properties of the external world are abstracted from actual ephemeral experience, then raised by decree to the status of fundamental principles, which are thought to be the basis from which that experience arises. This

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[12] Xenophanes: "Mortals suppose that the gods are born and have clothes and voices and shapes like their own. But if… horses… could paint with their hands and fashion works as men do, horses would paint horse-like images of gods…"

[13] For example, through the reductionist program, theoretical entities (photons, molecules, firing nerve cells, etc.)—which are conceptual outputs of the brain—are recycled as putative causes of the cognitive processes that result in those outputs.

circularity can occur in any realm of speculation, even religion, where the fundamental entities are spiritual. (God creates the world, which contains the beings who will create him.) In science, the fundamental entities are mathematically defined. This is no coincidence, since mathematics itself is the essence of this process of abstraction, reduction, and promotion of its concepts to the status of eternal truths. The physical is reconfigured as mental by the simple act of defining a realm. The world is thus remade in human terms, first by language and then through technology. In the beginning was the Word.

The germane question is how abstract concepts relate to ordinary experience. The problem is that a notion like something's real nature (essence or quiddity, as it is sometimes still called) is an idea grounded in ordinary phenomenal appearances, from which we derive our sense of realness in the first place. Something more fundamental is proposed to give rise to that ordinary experience. For example, the notion of "object" on the ordinary human scale (rock, cloud, tree) is metaphorically extended to form concepts of entities on the microphysical scale (atom, field, nerve cell). These theoretical entities are then held to be the basis from which emerges our experience of things on the ordinary human scale.[14] This circularity is implicit in the reciprocal relationship between reduction and emergence. If this were acknowledged, we might be more cautious about transferring concepts on the macro (i.e., human) scale to the microphysical—and then wondering how macro-scale appearances "emerge" from the micro-scale.

On the other hand, it might be argued that there is little choice: ultimately, we have only ordinary experience to go on, which is the basis of any extension by metaphor. How else to conceive "particles" but as tiny rocks? Of course, the shocking discovery that quantum objects do *not* behave like classical objects put the lie to that notion. Similarly, the shocking result of the Michelson-Morley experiment contradicted a literal medium for light. The puzzle may be less that some things do not behave according to expectation than that we expect them to in the first place! Apparently, our common-sense notions of reality on the ordinary scale cannot be presumed consistent with reality on other scales. Indeed, to the degree they exist only as ad hoc strategies that serve us as living organisms, they are not coherent in the first place. The brain concocts the daily illusion that the nature of things is given in phenomenal appearances. Questioning that, it then concocts the illusion that scientific concepts reveal the "true" nature of things.

There are similar problems at the other extreme of scale. We naturally tend to think of the universe as a giant object. But if objects are located in space, we must then wonder where the universe is located. Extrapolating from ordinary experience, beyond *this* universe there might lie others. While conceivable, these could be epistemically and causally off limits—which contradicts another expectation, that objects moving together in a common space must be able to interact with each other and with us. The notion that the universe (i.e. this totality of things in a common space) is infinite is no less troubling, for we have no experience of infinite objects. For all we know, there may also be no "bottom" level to the complexity of nature, which might be infinite all the way down as well as all the way up. Yet, we seek mathematically simple laws and an ultimately fundamental level, while nevertheless capable of wondering of what entities like quarks or strings might be composed. Such basic inconsistency does not normally impede or trouble science, much less mathematics, both of which carry on despite logical impasse.[15] The reifications built into metaphor are merely stepping stones, adopted or discarded as needed. The pragmatic faith that

[14] Only by circular logic could one be tempted to wonder what an electron "really" looks like—its color, for example—when 'electron' has been deliberately abstracted to be free from qualities such as color.
[15] Mathematics trumps impasses by incorporating them as new mathematical objects. E.g., the square root of two led to irrational numbers. Infinity made no sense at one time, but was eventually adopted as a number. Science often advances through similar acts of fiat, such as Einstein's postulation of the constancy of *c,* or Bohr's postulation of complementarity.

underwrites scientific practice is that what counts is quantification, measurement, and mathematical description. Which is to say: formal properties that enable us to predict and control nature and thus survive.

5. Ontology and reification

The ontology of physics considers what exists, is fundamental, and is real. Of course, all three of these qualifications are controversial in modern physics. Whatever scientists mean by these terms shapes the scientific ontology. Let us be concerned here, instead, with the psychological and explanatory role that an ontology plays, in contrast to purely formal (mathematical) description. Like verbs, laws tell us how things behave; and, like adjectives, various basic notions—such as particle or wave, mass or energy—are metaphors to describe how things relate. But we seek also to know the nouns: what those things *are*, what particles are made *of*. Waves in *what*? Such questions often seem to lead down a rabbit hole. Ironically, the *need* for an ontology points less to the structure of external reality than toward the structure of mind, with its basic tendency to reify.

As a kind of universal language, mathematics organizes scientific cognition in terms of formal attributes. That is possible because the aim is underlying *structure*, putatively invariant across observers precisely because it leaves out what that is structure *of*. (Leaving aside the daunting problems of identifying and agreeing upon structure, let us proceed on the assumption that there *can* be agreement.) One thing we can learn from scientific cognition is that ordinary perception too must be about structure. And one thing science can learn from ordinary cognition is this: just as the brain's activity causes phenomenality to emerge from structure in the world, by a similar legerdemain macroscopic structure in the world appears to emerge from the microscopic realm.

Reduction seeks basic structure (differences among appearances), while reification asserts what the differences are of. This dialectic reflects a basic dilemma of the self-conscious agent capable of abstract thought. It comes down to the schism between personal and interpersonal perspectives—reflected in the first- and third-person points of view. Reification means literally making a process, relation, or private datum into a public *thing*. The question of what the world consists of is closely related to the notion of substantiality and the biological need to recognize it. (Obviously, substantial things in the world can affect us seriously, and we can affect them in ways that benefit us.) Hence, dynamics charts the interactions of substantial things, characterized by mass, momentum, energy, etc.[16] In classical physics, this was paradigmatically the behavior of solid objects. However, contact between solid bodies did not account for all such behavior. Some things could apparently act at a distance, instantaneously without touching. It was reasonable to try to account for this with some intervening "substantial" medium—the field. Some thinkers accordingly believed the world must be a continuous plenum, with empty space an illusion; which posed the question: what, then, are discrete objects in such a continuum?

Before Faraday, the concept of 'field' was initially no more than a mathematical device, an alternative way to describe forces. It was perhaps inevitable to accord it some substantial and causal reality. Fields emanated from particles (and thus shared somehow in their substantiality), but reciprocally determined the motions of neighboring particles. Fields were the medium for the transmission of forces between one thing and another; on the other hand, the particle (or solid object) itself now seemed to be no more than a local disturbance within the field. The mystery of

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[16] These are descriptive terms that also imply substantiality. For an account of the notoriously problematic concept of *mass* in physics, see: John Roche "What Is Mass?" Eur. J. Phys. **26** (2005) 1–18; also: Max Jammer *Concepts of Mass in Classical and Modern Physics* (1961) Dover, 1997

action at a distance was resolved in terms of a notion of causation based on continuity, but at the cost of embracing a more subtle and mysterious entity that defied the traditional association of substance with discrete localizable objects. The question of what the field is made of was hardly more answerable than what the particle is made of.

Aristotle had proposed four types of causality: material, formal, efficient, and final. However, science retained only formal and efficient causes—a duality that tends to divide thinkers about what constitutes explanation. The notion of formal cause underwrote the emphasis on mathematics: things are sufficiently explained when you know the mathematical laws that describe their behavior. (In this essentially Platonic vision, the laws themselves have causal power to determine events.) Efficient cause, in contrast, sought to understand causal action in more mechanical terms: how the parts of substantial things pushed against each other to produce a change of state—a perceptible difference. The common ground of these distinct visions of causality is structure. (A machine has well-defined parts and structure; its behavior can be described mathematically because the *system* it embodies is a product of formal definition.) From a formalist point of view, it is not necessary to know the substance of which the parts are to be made (material cause)—which might be meaningless if nature were "parts all the way down." Nor is it necessary to know their purpose (final cause)—which might be unknowable if you are talking (as the early scientists were) about the "system of the world" as a divine creation.

6. Structural realism

Structural realism is the idea that structure is the essence of what can be considered objectively real—at least in the sense of what is measurable and interpersonally knowable. We need only be concerned with the observable relations between things—not what things are in themselves—provided agreement can be had about those relations, which are revealed in measured differences or change that should ideally be invariant across observers. Moreover, structure is form, which lends itself to mathematical description. Hence, the emphasis on covariant laws—mathematical expressions concerning variables whose values observers can agree upon through conventional transformations. But, *structure is also what sensory qualia and scientific measurements have in common.* Color vision, for example, discriminates wavelength (among other things), which can also be discriminated using instruments. In both cases what is detected are differences in the fine-grained structure of light. The instrument may (or may not) be more sensitive than the natural sense organ. The subjective experience of visual sensitivity is qualitative and first-personal, whereas the instrument's "reading" is quantitative and third-personal.[17] Accuracy aside, the information obtained is equivalent.

As Bateson remarked, information is a difference that makes a difference. The remarkable thing about "difference" is that people can agree about it, measure and quantify it, even when they disagree about what the difference is a difference *of*. For example, even though we can never confirm that we see colors the same way as others, we can agree about *differences* of color. Thus, structure is the fundamental concern of science, which is a third-person communication about the world. The ontological question of what the stuff *is* that *has* the structure is metaphysical rather than scientific. But, the reduction of appearances to structure leaves out the question of how such structure then actually gives rise, through some complementary process, to those appearances. That question cannot be answered purely in the domain of physics, but must include the subject's participation. Theories of how physical reality on one scale "emerges" from physical reality on

[17] Which simply means that it remains for a subject (the scientific observer) to read the instrument, producing a first-person experience. The input of the senses could also be said to be quantitative and third-personal—until it is "read" by the brain.

another scale, or at some other time, do not deal literally with phenomenal appearances, but rather with measurement, information or structure. Emergence, in the scientific context, means how one *structure* depends causally or conceptually on another; it does not propose to account for how phenomenality arises from structure as a product of analysis. Yet, there too, the observer's (or theorist's) participation must be included. For structure and cause, like phenomenal appearance, are mental constructs.[18] The mental operation of reducing phenomenal appearances to some ontology of structural elements parallels its operation of reducing one level of structure to another in the external world. In both cases, the inverse process of "emergence" implies a complementary operation of appearances arising from structure.

7. Example: space and time

Special Relativity is known as a revision of the concept of time. General Relativity is known as a revision of the concept of space. They both make observation relative to the circumstance of the observer. Yet Einstein's intention was to overcome the relativity of observation by finding a basis in which the laws of physics would take the same form for any observer. The key to this invariance hinged on questioning the received concept of time. Absolute time proved to be easier to debunk than absolute space, perhaps in part because space has always psychologically seemed more "objective" than time.[19] Einstein's realism also played a part, insofar as it was a commitment to something physical and independent of the observer. That required careful deliberation about the relationships between physical field concepts and mathematical space concepts. In any case, physics has understandably been reluctant to abandon space as a fundament. Yet, in modern physics and cosmology there have been movements in that direction, proposing that space emerges from something more fundamental underlying it. This conclusion dovetails (a) with Kant's pronouncement that space is not a property of the world-in-itself, but a "category" of thought pre-existing in the mind; and (b) with our heuristic portrait of the brain isolated in the skull. From each of these perspectives, the challenge is to characterize the irreducible fundament of what exists "in itself," common to all possible observers and independent of their (biological) constitution as well as their location and state of motion.

Physics is essentially mathematics applied to the physical world, so it is unsurprising that a major strategy in its quest involves metaphorically extending the natural experience of space to highly abstract conceptual "spaces," such as *phase space*, *n-dimensional manifold, tensor metric,* and *field*.[20] Geometric space began with Cartesian coordinates, and society adopted the convention that natural space correspondingly has three orthogonal "dimensions." Yet the concept of dimension (or degree of freedom) can loosely mean parameter, and any number of parameters can be conceived to constitute a "space" of *n* dimensions.[21] The amalgamation of time and space in a four-dimensional continuum treats the parameter *time* as another spatial dimension, effectively rendering all four parameters ontologically ambiguous. Both Cartesian space and Minkowskian spacetime are mathematical tools. Conceiving either as ontologically real is a metaphysical gesture. If the world-in-itself is to be defined in terms more fundamental than space and time, it will surely be with

[18] The fact that observers can agree upon the construct does not mean it is not constructed.
[19] Kant pointed out that time seems primarily an internal experience, whereas space seems primarily external. "Time is the a priori formal condition of all appearances in general. Space, as the pure form of all outer intuitions, is limited as an a priori condition merely to outer intuitions." [Kant, *Critique of Pure Reason:* The Transcendental Aesthetic, A34]
[20] The concept of field was a mathematical device before it was granted physically substantial reality. It emphasizes the environmental effect on the test particle rather than the earlier emphasis on the action-at-a-distance between particles. There are parallels in sociology, where emphasis can be on individuals or on the social field surrounding them. (Thanks to Irene Frieze for pointing this out in a private communication.)
[21] Orthogonality then simply means that the parameters are independent of each other.

parameters of some “deeper” mathematical abstraction that risks being similarly reified. Whatever that abstraction, it must be possible ultimately to retrieve ordinary experience from it.

Circularity poses no insurmountable obstacle to the reductive program, as attested by the tortuous history of the concept of mass. It did, however, temporarily stall Einstein’s thought about General Relativity, while struggling with the relationship between mathematical abstractions and physical reality. While the field concept was originally a mathematical tool, the electromagnetic field was adopted into the ontology of physics as “a new kind of physical reality,” which played a role in the development of Special Relativity.[22] According to the Newtonian understanding, as a new kind of extended “object,” a field still must be located “in space.” Einstein transferred the physical reality of the field concept to gravitation, which—with respect to other entities such as electromagnetic fields—could also take the place of the Newtonian space as their container or reference frame. It left the paradoxical question, however, of *where* the gravitational field itself was to be located. In other words, it was not so easy, even for Einstein, to divest himself mentally of the category of space as a container for events.[23] The philosophical problem is that there seem ontologically to be two sorts of thing: one physical (the field) and one conceptual or mathematical (the metrical framework). The former is framed in terms of efficient cause; the latter in terms of formal cause. In the end, he bit the bullet to accept the gravitational field as the only reasonable basis for a concept of space-time.

Some physicists have attempted to reduce time to space[24] and some to reduce space to time.[25] Now some are prepared to reduce both to something more fundamental. This is not just a matter of logical housekeeping. There seems also to be a belief that space and time “arise” in some ontic, historical, and causal sense—at some scale and at some moment in the early history of the universe. Space and time might “emerge” at the Planck scale or at the (“larger” and “later”) scale of quarks and hadrons, for example.[26] Both are current proposals about the evolution of the cosmos. Yet both involve obvious circularity, already presuming the existence of the time and the space that are supposed to come into being at a particular moment and at a particular scale.

An emergent origin of time and space has been made plausible by a proposed connection between entropy (thermodynamics) and gravitation.[27] Thermodynamic properties (e.g., temperature and pressure) emerge at the macroscopic scale from the statistical behavior of microscopic entities (e.g., molecules). Temperature is measured by some device that comes into equilibrium with the state of the substance measured, in a way that can be quantitatively indicated. In the natural meaning of temperature as a phenomenal experience, sense receptors come into equilibrium with what is sensed, but out of equilibrium with the ambient state of the organism. (E.g., water at body temperature does not register as either warm or cold.) Subjectively, temperature emerges for the organism as a difference that makes a difference. Similarly, pressure is evaluated according to the homeostatic needs of the organism. (Atmospheric pressure at sea level is not sensed.) On the other hand, the objective (theory-bound or instrumentally measured) temperature and pressure of a gas are deemed to reflect the average kinetic energy of its particles. These seem to be quite different notions of temperature and pressure. The meanings of emergence, though related, are correspondingly different.

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[22] Tian Yu Cao *Conceptual Development of Twentieth-century Field Theories* Cambridge UP, 1998, p93, quoting Einstein.

[23] This seems to lie behind his struggle with the Hole Argument. Compare his resolution of that problem to his decision in SR to simply *postulate* the invariant speed of light.

[24] E.g., Julian Barbour *The End of Time* Oxford UP, 1999.

[25] E.g., Lee Smolin (co-author R. M. Unger) *The Singular Universe and the Reality of Time* Cambridge UP, 2015

[26] E.g., Piotr Zenczykowski “Quarks, Hadrons, and Emergent Spacetime” arXiv:1809.05402v1 [physics.gen-ph] 2018

[27] E.g., Erik Verlinde “On the Origin of Gravity and the Laws of Newton” arXiv:1001.0785v1 [hep-th] 2010.

While the kinetic energy of a single molecule may be difficult to measure, the temperature or pressure of a single molecule has no meaning at all, since they are effects of large aggregates. Parallel effects occur in perception. A single molecule can hardly have a color or texture. Though deemed to have a definite frequency, a single photon cannot be perceived as having a color; nor can a single wave front of sound be perceived as having pitch. As registerable sensations, such qualia are collective, interpolating the behavior of multiple nerve firings. If space and time are emergent in a similar sense as temperature/pressure, then perhaps they too are collective effects of scale. Then the process by which the *brain* interprets neural events—to experience a quality such as color or pitch—is paralleled by a process in which the *physicist* interprets micro events in the external world that give rise to macroscopic properties such as temperature and pressure.

Space and time cannot "emerge" from some deeper level if they are not first reducible to such a level. We would be at an impasse—just as we would be if we took temperature or pressure to be irreducible realities rather than measurable collective effects of molecular motions.[28] Let us instead approach emergence in an epistemic rather than an ontic sense. Let us treat space and time, like temperature and pressure, as functions of measurement. Light (or some equivalent physical vehicle for transferring information across distance) is the universal yardstick,[29] without which the concepts of space or time have no more meaning than the concepts of temperature or pressure can have without a physical means to detect them. Light is the measure of distance for a visual creature in a cosmos that is more like a gas than a rigid body. Without rigid rulers, "distance" can be interpreted either as a spatial or temporal interval. In that sense, space and time "emerged" when light did—namely, when electrons became bound in atoms so that the universe was no longer opaque to transmission.[30] This too involves a PCD, since—in order to explain how space and time emerge physically—we are obliged to assume their prior existence: a plasma existed in space at the time recombination occurred. This presumption involves the same circularity as in the case of the brain. In picturing its isolated situation within the skull, we nevertheless stand outside the picture to conceive a world in which the skull exists, in order to explain how the brain arrives at its (our) picture of that world. In picturing the emergence of space and time, we must assume space and time while standing mentally outside it.

8. Example: phenomenality

Consciousness is widely considered to emerge from the activity of the nervous system—the mental from the physical. "Emergence" in that context is little more than hand-waiving, however, since it remains a mystery how that takes place. Yet, we have a model for it in the mental operation we have been considering: the sort of deduction that is the inverse of reduction. That is a conscious process, of course, whereas the parallel process of emergence in the brain is unconscious (insofar as the brain itself is not aware of it). Here again, we see a PCD, since the elements that are thought to produce consciousness are themselves products of conscious thought.

The crux of the problem of consciousness is point of view. The scientist's point of view can scarcely imagine how the "inert" matter that is the object of scientific study can have a point of view of its own. Yet, clearly scientists' own brains are held to be responsible for their conscious ideas; hence, the brain itself must be accorded a point of view. The scientist as a conscious person is in the same epistemic situation as his or her own brain. The creative and logical approach of both

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[28] As scientists did before the kinetic theory and some positivists who opposed the atomic theory did in the 19th century.

[29] Although Einstein developed Special Relativity in terms of macroscopic clocks and rigid rulers, the postulated constancy of c rendered light the only feasible yardstick for cosmic distances.

[30] This also marked the beginning of the cyclical atomic process through which time is now measured.

must be similar. In one sense, the world is a black box for both; in another sense, the brain is the black box.

In the 19th century, Herman Helmholtz proposed the idea of 'unconscious inference', intuitively bridging the gap between these perspectives by putting the scientist in the shoes of the brain, so to speak. Here, we propose that such a strategy is the way to get traction on the apparent gulf between the mental and the physical. The computational metaphor[31] of mind extends Helmholtz's intuition, since the programmer tries to model the *brain's* operations as the sort of logical operations that the *person* would employ to infer a "realistic" picture of the world. In other words, scientific cognition and sensory cognition are analogous. Phenomenality emerges from sensory input in the same way that the scientific worldview emerges from research data—by acts of inference made by an agent. What the scientist does recapitulates what the brain does; and what the scientist thinks the brain is doing recapitulates what the scientist is doing. Conscious and unconscious inference can mutually inform each other. The brain produces phenomenality (e.g. qualia) in a way that parallels how the scientist produces theories of the world—and vice-versa. The emergence of consciousness from neural activity is no more (or less) mysterious than the emergence of macroscopic physical phenomena from microscopic ones. In both cases, an agent behind a curtain uses smoke and mirrors to produce the effect of emergence.

9. Formal versus efficient cause

Efficient and formal causes are both useful notions for prediction, but efficient cause is committed to material *substance* whereas formal cause regards observed *pattern* or proposed *form*. Formal cause considers the laws expressing patterns and properties, without concern for what the patterns are patterns *in* or properties are properties *of*. No doubt this is an important reason for the essential role of mathematics in the sciences, since equations neatly express the patterns and relationships we know as laws.[32] This "unreasonable effectiveness of mathematics" is underwritten by the Platonic notion that the ideal ("form") is what metaphysically exists. Formalism has thus been a persistent thread in scientific thinking from the earliest times—for example, Pythagoras' then Kepler's number mysticism and Galileo's insistence upon mathematics as the language of nature. It manifests in modern times in considering 'information' (or entropy) to be a fundamental entity like energy or mass. Energy and mass in turn encode and reify the sheer kinematics involved in observed interactions of apparently substantial things. Kinematics means change of *distance*—nominally in space with respect to time.

The concept of a *metric* provides a purely formal definition of "distance," which can be read simply as *distinctness* (i.e. difference between separable elements). It need not imply the usual spatial or temporal meaning. A theory proposing to account for physical reality in terms more fundamental than space and time would constitute a formalism whose elements might be abstract distinctions rather than conventional positions and times and their derivatives. Yet, as in the case of a metric, those abstract elements could be *interpreted* (in the logico-mathematical sense) as physical distances in space or time. Such an interpretation is an *intentional act*.[33] It would presumably map the *physical* processes by which time and space appear to emerge from some deeper physical level.

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[31] The enactivist movement legitimately criticizes the computational metaphor, largely because the computer (so far) is disembodied. That is irrelevant to the present argument however, and one should not throw out the baby with the bathwater.

[32] The efficient sense of cause also persists, and equations (laws) are sometimes granted power in a material rather than purely descriptive sense. That is, the laws (equations) themselves are held to have causal power over matter.

[33] "Interpretation," in the logical sense, is "an assignment of meaning to the symbols of a [purely syntactic] formal language." [Wikipedia: Interpretation (logic)]. Such assignment is the intentional act of an agent. Presumably the brain's "computations" employ some process analogous to the logician's assignment of meaning to symbols.

Alternatively, it could also describe the *cognitive* emergence of space and time—the processes by which the mind/brain interprets sensory data to give rise to the phenomenal experience of an external world with/in space and time. Hence, such a theory of emergent space-time, describing the physical evolution of the world, could shed light on how the brain produces our experience of the world—and vice-versa. The scientist's interpretation of a formalism parallels the brain's interpretation of sensory input: both involve intentional acts—performed by the scientist in the one case, by the brain in the other.[34] In the 19th century, temperature emerged from motion; in this century, motion (i.e. space and time) emerges from temperature.[35] Phenomenal experience emerges from the brain's interpretation of sensory input.[36] In all cases, emergence involves the interaction of subject and object, and is neither purely mental nor purely physical.

10. Conclusion

As organisms, we are natural-born realists, concerned with what goes on in the apparently external world. The naïve realism of the brain produces its vision of external reality presented in perception. Given our fundamental epistemic situation, the subject can hardly think about this process of production without indulging in circularity. The same is true of scientific realism. On the one hand, it produces a vision of reality redefined in theory. On the other, it tends also to demand an interpretation in the original realist terms of familiar experience from which theory was derived. In both cases, the circularity can be side-stepped by relaxing the demand for an objectivity that excludes the subject. Phenomenality then emerges from the brain's intentional acts, which imaginatively "fill in" the bare bones of the structure that science reductively posits.[37] That is, the brain produces a virtual reality it intentionally experiences as real. Similarly, we are free to "fill in" the reality of the theoretical constructs that science proposes, in such a way that one physical reality appears to emerge causally from another. In both cases, emergence involves the participation of a subject.

The concept of emergence is significant in physics in two senses: as a transition between scales and as the inverse of conceptual reduction. In psychology and brain science, phenomenal experience mysteriously emerges as a product of the brain's activity. This similarly involves a transition from one scale to another—and also the inverse of a reduction. These two "emergences" are mutually informing. They both involve the circularity I have called the problem of cognitive domains, which results from our basic epistemic isolation from "the world-in-itself." They both involve the conjoint role of subject and object, in parallel forms of cognition. Phenomenal emergence seems mysterious until the brain's intentionality is considered (the mind-body problem). Similarly, physical emergence seems mysterious until the intentionality of the theorist's prior reductive acts is considered. They are two sides of the same cognitive coin.

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[34] In addition to generalizing and abstracting the perceived properties of things into idealized essences, a crucial step in formalization is to then *assert them by fiat*, effectively as elements of a formal system. The empirical generalization becomes a *definition* or *axiom*, now in the domain of the mental acts of an agent instead of the domain of data about the world. Such assertion by fiat distinguishes logical from empirical truth.

[35] See Verlinde, op cit

[36] See my paper: "How the Brain Makes Up the Mind: a heuristic approach to the Hard Problem of consciousness" (2018) [https://philpapers.org/rec/BRUHTB-3, also archived on my website: www.stanceofunknowing.com]

[37] *Pace* Dennett, whose own realism seems to preclude this idea.