TWO THEORIES OF DECOHERENCE

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Abstract

Theories of decoherence come in two flavors—Platonic and Aristotelian. Platonists grant ontological primacy to the concepts and mathematical symbols by which we describe or comprehend the physical world. Aristotelians grant it to the physical world. The significance one attaches to the phenomenon of decoherence depends on the school to which one belongs. The debate about the significance of quantum states has for the most part been carried on between Platonists and Kantians, who advocate an epistemic interpretation, with Aristotelians caught in the crossfire. For the latter, quantum states are neither states of Nature nor states of knowledge. The real issue is not the kind of reality that we should attribute to quantum states but the reality of the spatial and temporal distinctions that we make. Once this is recognized, the necessity of attributing ontological primacy to facts become obvious, the Platonic stance becomes inconsistent, and the Kantian point of view becomes unnecessarily restrictive and unilluminating.

1 INTRODUCTION

Theories of decoherence come in two flavors—Platonic and Aristotelian. A Platonist is one who grants ontological primacy to concepts and mathematical symbols, especially those by which we describe or comprehend the physical world. An Aristotelian is one who grants ontological primacy to the physical world that we describe or comprehend through concepts and mathematical symbols. (This is all the reader needs to know about Platonists and Aristotelians.) True to its label, the Platonic theory of decoherence attaches ontological primacy to the (unitarily evolving) quantum state of the universe. Its aim is to explain why, on macroscopic scales, the world looks classical to observing systems. The Aristotelian theory, on the other hand, attaches ontological primacy to facts. It views quantum mechanics as a theory exclusively concerned with the statistical correlations between property-indicating facts or, equivalently, between properties indicated by facts. Its aim is to explain why the positions of macroscopic objects are so correlated that they not only supervene on the property-indicating facts but also constitute them.

Decoherence [1, 2] is not a part of any interpretational strategy. It is a physical phenomenon [3, 4] predicted by quantum mechanics and, like quantum mechanics itself, in need of an interpretation. That is why there are two theories of decoherence, at the least. This article
is concerned with the conceptual differences between these theories, rather than with quantitative issues, on which both theories agree. The two theories are discussed in Secs. 2 and 3, respectively.

Section 4 introduces a third species of physicist, the Kantians, who favor an epistemic interpretation of quantum states. Since the early days of quantum physics it was the Platonists and the Kantians who carried on between them the debate about the meaning of quantum states, the former looking upon them as states of Nature, the latter proclaiming them to be states of knowledge. Both positions are equally unpalatable to the Aristotelians—mostly experimentalists who worry about the state of their apparatus rather than the state of their knowledge, and who need quantum states for only one purpose, namely to calculate the probabilities of measurement outcomes. For an Aristotelian, quantum states are encapsulations of statistical correlations between property-indicating facts—correlations that are as objective as any of the deterministic regularities encapsulated by the dynamical laws of classical physics. While this is all there is to a quantum state, it is by no means all there is to quantum mechanics, for these correlations contain a message of considerable ontological significance, a message concerning the spatial and temporal differentiation of the physical world.

The label “Aristotelian” for the interpretation preferred by this author is appropriate for another reason: It was Aristotle who first thought of the divisions that we mentally project into the physical continua as existing potentially, rather than actually, unless their actuality is warranted by something not found in the continua themselves. This something is a position-indicating fact. Quantum mechanics—the theory of the correlations between property-indicating facts—tells us under what conditions and to what extent our conceptual partitions of space and time have counterparts in the physical world.

2 DECOHERENCE: THE PLATONIC VERSION

The theory of decoherence discussed in this section is, true to its Platonic underpinnings, an idealization—an archetypal Form (eidos) not perhaps found in its noumenal purity in the writings of any actually existing einselectionist (einselection = environment induced superselection). No concrete models are considered, no calculations of decoherence scales or recurrence times are carried out. There is no reference to POVMs (positive operator valued measures), despite their obvious appropriateness to actual measurement situations, in which the orthogonality of the indicating properties rarely implies the orthogonality of the indicated properties. (For quantitative studies of decoherence see Ref. and work cited therein. For an account of decoherence based on POVMs see Ref.) As far as the issues considered in this article are concerned, these quantitative or formal niceties do not matter.

A Platonist attaches ontological primacy to concepts and mathematical symbols. The obvious candidate for representing what a Platonist regards as ultimately real is the state vector $|\Psi(t)\rangle$ of the Universe. Since there isn’t any apparatus external to the Universe, this evolves strictly according to $i\hbar \frac{d}{dt} |\Psi\rangle = \hat{H} |\Psi\rangle$ with some Hermitean operator $\hat{H}$.

For Platonists the existence of concrete individuals has always been an embarrassment. It
ought to be derived from what is ultimately real, yet it cannot be derived from general terms inasmuch as general terms do not imply the existence of singular terms. To get horses out of horseness Plato needed to invoke

that which is duly to receive over its whole extent and many times over all the likenesses of the intelligible and eternal things, . . . the mother and Receptacle of what has come to be visible and otherwise sensible, . . . a nature invisible and characterless, all-receiving, partaking in some very puzzling way of the intelligible and very hard to apprehend. [10]

Modern Platonists sidestep the problem of the existence of individuals by pointing out that the classical demeanor of the macroworld can be understood only in terms of correlations between individual systems [8]. The Platonic account of decoherence begins with the assumption that the Universe is a collection of interacting systems. Certain systems possess a (limited) ability to gather and retain information. The acquisition of information about a system $S$ by an information gathering system $A$ (the “apparatus”) takes place in an “environment” $E$. If $S$ is sufficiently large or massive, it cannot be isolated from $E$. The interaction Hamiltonian $\hat{H}_{SE}$ then depends on the position of $S$ relative to $E$ but not on the momentum of $S$ relative to $E$.

As a consequence, $E$ acquires information about the (successive) positions of $S$, and only about these, and this information is redundantly recorded in $E$.

Suppose that $A$ is about to measure the position of $S$, that the states $|S_i\rangle$ are the localized states of $S$ which $A$ can distinguish, and that the spatial resolution of the measurement does not exceed the resolution with which $E$ monitors the position of $S$. Then the measurement interaction causes $S+A+E$ to evolve according to

$$
\sum_{i=1}^{N} c_i |S_i\rangle |A_0\rangle |E_i\rangle \rightarrow |\psi_{SAE}\rangle = \sum_{i=1}^{N} c_i |S_i\rangle |A_i\rangle |E_i\rangle ,
$$

where $|A_0\rangle$ represents the neutral state of the pointer, and the kets $|A_i\rangle$ represent the pointer as indicating a possible measurement result. If the resolution with which $E$ monitors the position of $S$ sufficiently exceeds the resolution of the apparatus, the kets $|E_i\rangle$ will be as good as mutually orthogonal, so the state of $S+A$ will be almost exactly equal to the reduced density matrix

$$
\rho_{SA} = \sum_{i=1}^{N} |c_i|^2 |S_i\rangle \langle S_i| |A_i\rangle \langle A_i|
$$

obtained by a partial trace on the environment indices. The measurement is therefore repeatable. Performed again after a time $\Delta t$ still short enough for the system’s self-evolution (due to the Hamiltonian $\hat{H}_S$ alone) to be negligible, it will yield the same result. The result is predictable because the information acquired by $A$ merely confirms information already in possession of $E$, and because within the time span $\Delta t$ this information changes negligibly.

Now suppose instead that $A$ measures a nonlocal observable—an observable $Q$ whose eigenstates are superpositions of localized states of $S$ superselected by $E$. In this case the measurement is no longer repeatable once the decoherence time $\Delta t_d$ has passed. For a macroscopic
object $\Delta t_d \ll \Delta t$. The environment’s incessant monitoring of $S$ almost immediately destroys the coherence of the eigenstates of $Q$, so that the information acquired by $A$ cannot be used for making predictions.

Classical objects follow trajectories in phase space (time-ordered sequences of positions and momenta) that are predictable, at least in the absence of chaos. Macroscopic objects behave much like classical ones, and einselection is the reason why. $E$ keeps monitoring the position of $S$ with a limited spatial resolution. Owing to this limited resolution the position of $S$ remains somewhat uncertain, and the momentum of $S$ retains some of its sharpness. As a consequence, the trajectory of a macroscopic object $S$ in phase space is predictable, to within the spatial resolution achieved by $E$, for some time $T$. In the absence of chaos $T$ is astronomical, while for a chaotic system it can be quite short. (Without decoherence the orientation of Hyperion, Saturn’s chaotically tumbling moon, would have to be described by a coherent superposition of orientations that differ by $2\pi$ after approximately 20 years. [11, 12])

Plato acknowledged two kinds of reality, which we may call being and existence. Being—the most general term—is what is real per se. It is inherited by all general terms. Existence is what those things have to which singular terms refer. General terms are but do not exist. Individual things exist because they are (delimited) portions of the Receptacle, and because they partake of the being of some general term. Since individual things owe their existence partly to something—the Receptacle—that by itself neither is nor exists, their reality is at bottom illusory. As Plato put it, while one may have opinions about them, one cannot have any knowledge of them.

For the Platonic einselectionist, it is the deterministically evolving universal state vector $|\Psi(t)\rangle$ that is real per se. States of a component system are not real per se but they may exist [13]. The key criterion is predictability [14]: A state of $S$ exists if and only if an apparatus $A$ can come to “know” it without “disturbing” it. The only states that satisfy this criterion are the einselected states. Hence only they exist. The universal state $|\Psi(t)\rangle$ is but does not exist, for want of both an environment that could make it predictable and an apparatus that could come to “know” it. Einselected states seem to be intrinsically possessed and merely revealed by observation, but at bottom this too is an illusion. There are no intrinsically possessed states. There are only correlations between states. Einselected states exist, not because they are intrinsically possessed, but because they are predictably correlated. Their existence supervenes on the correlations between them. Considered in themselves, apart from their correlations, they exist as little as Plato’s Receptacle does according to Plato.

The diagonal density matrix $\rho_{SA}$ contains conditional information: If (and only if) $S$ is in the state $|S_i\rangle\langle S_i|$ then (and only then) $A$ is in the state $|A_i\rangle\langle A_i|$. This is true for every $i$. What determines the truth values of the antecedents? Not $E$, for the environment only makes sure that each of those states is predictable; it does not single out a particular $i$. The einselectionist’s definition of existence implies that all of those states exist in an index-specific sense: It is true for all $i$ that both $|S_i\rangle\langle S_i|$ and $|A_i\rangle\langle A_i|$ “$i$-exist,” and that neither of them “$j$-exists” unless $j = i$. Thus if $A$ acquires information about the state of $S$, it comes to exist in $N$ different senses or, equivalently, in $N$ different worlds or, equivalently, in $N$ different minds [13].

Existence is relative not only in that it comes in different, index-specific kinds but also in
that there can be more or less of it. The existence of a state can be quantified by the redundancy with which it is recorded elsewhere in the Universe, or by the number of times it can be found out independently. Relative existence becomes absolute and unsubvertible only in the limit in which the redundancy goes to infinity and cloning of unknown states becomes possible [8].

3 DECOHERENCE: THE ARISTOTELIAN VERSION

The first thing a modern Aristotelian would stress is the extra-theoretical nature of reality. The laws of classical physics do not uniquely determine the actual world; they determine a set of nomologically possible worlds, of which the actual world is one. Classical physics has no criterion for picking out the actual world—the one that is not only possible but also real. Nor has quantum physics. Like the actual course of events in classical physics, the universal state vector $|\Psi(t)\rangle$ depends on initial conditions, and for all we know these are not uniquely determined by physical law. In addition to this, each nomologically possible evolution of $|\Psi(t)\rangle$ is associated with a considerable number of classical domains in which macroscopic objects follow quasi-definite trajectories in phase space, as the previous section has shown. Since these classical domains exist in different senses, it would be incorrect to say that they coexist, for things that coexist share the same kind of existence. The sense in which these classical domains “exist” and “coexist” is none other than the sense in which possible worlds exist and coexist. (Reminder: Saying that a possibility $X$ exists is the same as saying that $X$ is possible.)

The central role played by probabilities in most interpretations of the formalism of quantum mechanics suggests that the first question that ought to be addressed is, probabilities of what? Of possibilities, no doubt, but not every possibility can be assigned a Born probability. There is the possibility that an attempted measurement succeeds—that it yields a result. And then there is the possibility that a successful measurement yields this particular result rather than another. Born probabilities are associated exclusively with possibilities of the latter kind. The trace rule presupposes facts not only because it assigns probabilities on the basis of property-indicating facts (the “preparation”) but also because it assigns probabilities to properties on condition that one of them is indicated [14, 17, 18].

For this reason Aristotelians attach ontological primacy to facts—actual events or states of affairs involving properties of actually existing material objects. What is ultimately real, according to them, is such actual events as the click of a counter and such actual states of affairs as the orientation of a pointer needle. These facts do not simply reveal properties that are intrinsically possessed. On this point Platonists and Aristotelians agree: There are no intrinsically possessed properties. Their disagreement concerns the necessary and sufficient conditions for the existence (i) of possessed properties and (ii) of probabilities.

The Platonic view is that states and the properties they connote exist if and only if they are predictably correlated. The existence of the correlata supervenes on the correlations, subject to einselection. Einselection makes sure that the existing correlata constitute separate classical domains following quasi-definite trajectories in phase space. For Aristotelians properties exist if and only if their possession is indicated. The existence of the correlata supervenes on the facts that
constitute the classical domain. In other words, the values of quantum-mechanical observables are extrinsic: No property is a possessed property unless it is an indicated property \[16, 17, 18\].

As regards probabilities, the Platonic view is (i) that they exist if and only if they are associated with possible states, and (ii) that states are possible if and only if they are predictably correlated \[8\]. The Platonic conditions under which states are possible are thus the same as those under which states exists, which again shows that Platonic existence is nothing but nomological possibility. To the Aristotelian way of thinking property-indicating facts determine unitarily “evolving” density matrices whose sole purpose it is to assign probabilities to the possible outcomes of possible measurements at specified times. Born probabilities exist only for such (actually or counterfactually obtained) outcomes. (A “measurement outcome” is a property-indicating fact. It is irrelevant whether this came about with the help of experimenters, or whether there is anyone around to take cognizance of what is indicated.)

The word “specified” is essential. The parameter \(t\) on which (in the Schrödinger picture) a density matrix \(\rho(t)\) depends does not refer to a continuous succession of self-existent and intrinsically distinct moments. It refers to the specified time of measurement of a specified observable or set of observables. \(\rho(t)\) is not something that exists or obtains throughout some time span and alternates between unitary evolution and collapse. It is an algorithm for assigning probabilities to the possible outcomes of possible measurements. The quantum formalism does not “know” which observables are measured and when they are measured. Before it can tell us the probabilities associated with the possible outcomes of a measurement, we must tell it not only which observables are measured but also the time at which they are (successfully) measured \[16, 17, 18\].

Accordingly, the trace formula

\[
p(G_S, G_A, G_E, t) = \text{Tr}(|\psi_{SAE}(t)\rangle\langle\psi_{SAE}(t)|P_SP_AP_E)
\]

gives the joint probability that \(S\), \(A\), and \(E\) possess the respective properties \(G_S\), \(G_A\), and \(G_E\) at the time \(t\) provided that there are facts that indicate whether or not these properties are possessed at the time \(t\). (\(P_S\), \(P_A\), and \(P_E\) are the corresponding projection operators in the respective Hilbert spaces of \(S\), \(A\), and \(E\).) Yet if \(E\) includes everything but \(S+A\), there is nothing external to \(S+A+E\) by which properties of \(S\), \(A\), and \(E\) could be indicated. Aristotelians therefore need to show that a part of the environment admits of two conceptual representations, a density-matrix representation that serves to assign probabilities to its possible properties, and a “classical” representation according to which certain properties are intrinsically possessed and therefore capable of indicating something.

Platonists accept unquestioningly that the parameter \(t\) on which a density matrix depends refers to a continuous succession of intrinsically distinct moments. From this (from the Aristotelian point of view erroneous) assumption there arises the need of a criterion for distinguishing states that exist at a time \(t\) (along with the properties or the values they connote) from states that do not exist at the time \(t\). Since in reality \(t\) refers to the time of a measurement, this need is spurious. A quantum state is not something that exists at a time \(t\), anymore than the probability of finding a particle in a region \(R\) is something that exists inside \(R\). Accordingly,
we do not need decoherence to tell us when quantum states exist. We need it to establish the consistency of the aforesaid two representations of the environment.

Given the extra-theoretical nature of reality, a choice has to be made. Platonists place the burden of reality on \( |\Psi(t)\rangle \), the Hamiltonian \( \hat{H} \), and certain other theoretical accouterments, and attribute the “emergence of classicality” to the interactions between observing systems, observed systems, and their environment. Aristotelians regard it as inconsistent (i) to hitch reality to a formalism whose sole purpose it is to encapsulate correlations between property-indicating facts, and (ii) to believe that the reality of facts is an inferior kind of reality, confined to what observing systems can learn. They place the burden of reality squarely on the facts, including those on which the values of quantum-mechanical observables supervene—without denying that at bottom all properties are extrinsic: Even the Moon is there only because of the (myriads of) facts that betoken its whereabouts [19]. Position-indicating facts constitute its being there. This obligates the Aristotelians to demonstrate the existence of a special class of macroscopic objects whose positions are at the same time—for all quantitative purposes rather than merely all practical ones—intrinsic.

What the Platonic theory of decoherence has established is that all nomologically possible worlds look (almost) classical on macroscopic scales: Sufficiently large and/or massive objects follow quasi-definite trajectories in phase space. This result depends on the correlations between \( S \), \( A \), and \( E \) regardless of the ontological status of the correlata. For Aristotelians the correlata are properties indicated by facts. Some of these, including the positions of sufficiently large and/or massive objects, are predictably correlated. Every time the position of such an object is indicated, its value is consistent with a definite trajectory in phase space. We can therefore conceive of the positions of such objects as forming a self-contained system of positions that “dangle” causally from each other, rather than ontologically from position-indicating facts. We can ignore their extrinsic nature and consider them factual per se. We can then attribute the possession of any property to its being indicated by the position of at least one such object. This is how an Aristotelian would establish the existence of a special class of macroscopic objects whose positions are at the same time (at bottom) extrinsic and (for all quantitative purposes) intrinsic [3, 16, 18]. These positions are the properties of which facts are made—or, to put it more prosaically, the properties to which observer-independent factuality can be consistently attributed.

In the Platonic scheme of things the correlations, as aspects of the universal state vector, have ontological priority over the correlata. What is studied, accordingly, is the information that one system can obtain about another, via the correlations. The central result of the Platonic theory of decoherence—that all nomologically possible worlds look (almost) classical on macroscopic scales—is therefore limited to information that is accessible to observing systems. In the Aristotelian scheme of things, the correlata enjoy an observer-independent reality. Properties that are not predictably correlated exist (independently of observers) because they are indicated by properties that are so correlated, and because the latter can be treated as factual per se. According to the Platonic theory the classical domain looks to \( A \) like a system of intrinsically possessed properties. According to the Aristotelian theory the classical domain behaves like a
system of intrinsically possessed properties, and for this reason we can consider it factual per se—we can attribute to it that extra-theoretical something which sets off the actual world against all merely possible ones.

Einselection actually serves the Aristotelians better than it serves the Platonists. According to the latter, the diagonality of a density matrix is necessary for the existence of states. But relative to the intrinsically and infinitely differentiated temporal background presupposed by the Platonists the off-diagonal terms never vanish completely, though they may become very small very fast and remain so for a very long time. Consequently, states not only exist in different senses (corresponding to different possible worlds) but also in different degrees. No state exists absolutely since this would require strictly vanishing off-diagonal terms.

Aristotelians, on the other hand, can point to the finite spatial differentiation of the physical world \[5, 16, 18\], which implies that no physical system can, during a finite time span \(T\), be in an infinite number of states such that each state is distinct from (orthogonal to) its immediate predecessor. Even the environment does not pass through infinitely many distinct states in a finite time, so there is nothing that could indicate the position of a macroscopic object \(M\) at an infinite number of distinct times during \(T\). The relevant question therefore is not whether certain terms that enter into the calculation of probabilities vanish. The relevant question is, are the indicated positions of \(M\) consistent with a classical trajectory? If infinitely many successive positions were indicated, each having a small prior probability of being inconsistent with a classical trajectory, some facts would be inconsistent with a classical trajectory unless those terms vanished strictly. But since no more than a finite number of successive positions are indicated, those terms only need to be sufficiently small for it to be highly probable that all indicated positions are strictly consistent with a classical trajectory. This is why Aristotelians can claim that macroscopic objects exist, and that by definition they follow definite trajectories in phase space, not just for all practical purposes but for all quantitative ones \[5, 16, 18\].

Platonists have to live with the danger of “recoherence.” Correlations can in principle disappear; memory states can vanish without a trace; nothing exists for sure. For Aristotelians these dangers do not exist. A fact is a fact. If something indicates the possession, at a time \(t\), by a system \(S\) or an observable \(Q\), of a property \(G\) or a value \(q\), then it always has been and always will be true that \(S\) has the property \(G\), or \(Q\) has the value \(q\), at the time \(t\). There is nothing subvertible or reversible about this.

4 BEYOND DECOHERENCE

A consistent theory of the physical continuum that embraces Aristotle’s insights does not exist to this day; it would surely have to be a quantum theory.—C.F. von Weizsäcker \[20, p. 350\]

The label “Aristotelian” is appropriate for another reason. It was Aristotle who inaugurated the potential conception of the continuum and of the infinite, which avoids the paradoxes engendered by the conception of an actually existing infinite and of an infinitely and intrinsically differentiated continuum—from those pointed out by Zeno to those arising from the concept of
the set of all sets \[ \text{p. 346} \] \[ \text{p. 346} \] \[ \text{p. 346} \].

From the point of view of a present-day Aristotelian, the concept of an intrinsically and infinitely partitioned space or time is as inconsistent with quantum mechanics as the concept of absolute simultaneity is with special relativity \[ \text{[5, 16, 17]} \]. It is physical systems that are partitioned spacewise and timewise, or else it is for physical systems that space and time are partitioned. Even for a macroscopic object \( M \) space is only finitely partitioned, in the sense that no finite region \( R \) can be considered partitioned into infinitely many regions \( R_i \) such that (indicated) truth values exist for all propositions “\( M \) is inside \( R_i \).” As a consequence, time too is only finitely partitioned, in the sense that no object passes through an infinite sequence of successively distinct (orthogonal) states in a finite time span, as was pointed out in the previous section.

The finite spatial and temporal differentiation of the physical world is arguably the most significant ontological implication of quantum mechanics \[ \text{[5, 16, 23, 24]} \]. It is a consequence of the indefiniteness of all relative positions which, together with the exclusion principle, “fluffs out” matter, and which entails the extrinsic nature of the values of quantum-mechanical observables \[ \text{[5, 18]} \]. It implies that the world is not built bottom-up, on an infinitely differentiated space, out of locally instantiated physical properties. The cardinal error of the Platonic theory is its unquestioning acceptance of the field-theoretic notion of an intrinsically and infinitely differentiated space and time, without which not deterministic evolution could be postulated for any function of space and/or time coordinates. Spatial distinctions supervene on the facts, and the facts never warrant the actual existence of sharply bounded regions or exact positions. Therefore even the positions of macroscopic objects are fuzzy—but only in relation to an unrealized degree of spatial differentiation (that is, only in relation to an imaginary backdrop that is more differentiated spacewise than is the physical world). The regions over which the position of a macroscopic object is “smeared out” exist solely in our minds. That is why we can treat the positions of macroscopic objects as intrinsic.

The reason why we must treat them as intrinsic is that otherwise there wouldn’t be any positions. The positions of things are physically defined by, and relative to, the positions of macroscopic things—and never more sharply than the latter. Macroscopic detectors are needed not only to indicate the possession of a position but also to realize (make real) an attributable position. By the same token, macroscopic clocks, indicating time by the positions of macroscopic hands, are needed not only to indicate the time of possession of a property but also to realize that time.

It thus appears that ever since the introduction of quantum states into physics we have been asking the wrong questions. The debate continues about whether a wave function \( \psi (x, t) \), \( x \) being a point in a configuration space, represents a state of Nature, as the Platonists have it, or a state of knowledge, as the Kantians \[ \text{[5, 25, 26]} \] believe. It represents neither. The real question is not whether \( \psi \) represents an existing state of whatever kind but whether or not \( t \) and \( x \) refer to an intrinsically and infinitely differentiated physical manifold. The real issue is not the reality of quantum states but the reality of the spatial and temporal distinctions we make.

The reality of these distinctions is both contingent and limited. The regions \( L \) and \( R \) defined
by the two slits in a double-slit experiment with electrons are real and distinct for an electron \( e \) if and only if the truth values of the propositions “\( e \) went through \( L \)” and “\( e \) went through \( R \)” are indicated by facts—that is, if and only if they have truth values. Only possessed positions exist, and possessed positions supervene on facts. So do the times at which they are possessed. So does the spatiotemporal aspect of the physical world, which consists of the positions of things and the times at which they are possessed. And these positions and times never have perfectly sharp values, as they would have to if space and time were intrinsically and infinitely differentiated. (If \( L \) and \( R \) were distinct per se, no electron could go through a double-slit without going through a particular slit and without being divided by its passage through the slits. The intrinsic distinctness of \( L \) and \( R \) would imply the existence of distinct parts.)

The reality of an intrinsically and infinitely differentiated space and time is taken for granted by both the Platonists and the Kantians. Combined with the doctrine of determinism and a naive mathematical realism, this leads the former to confine the reality of facts to the information that observing systems can obtain. (Apparently this does not deter systems with a Platonic turn of mind from attributing to statistical regularities distilled from observations a stronger, independent kind of reality.) Combined with the Kantian doctrine that space and time lie in the mind of the beholder, it prevents the latter from arriving at a consistent observer-independent conception of the physical world. Einselectionists and information fundamentalists thus have much more in common than they realize or are willing to admit. Proceeding from the same misconception, both arrive at the philosophically defunct dichotomy of a real world “out there” and a known world “in here.”

Caught in the crossfire between Platonists and Kantians, Aristotelians must fight on two fronts. Because of their insistence on the observer-independent reality of the physical world, the Kantians look upon them as Platonists, and because of their insistence that quantum states are nothing but probability measures, the Platonists look upon them as Kantians. A central claim of the Aristotelians is that the regions over which the position of a macroscopic object is “smeared out” exist solely in our minds. From this one might conclude that all of space lies in the mind of the beholder, and that Aristotelians are therefore crypto-Kantians, but this is a non sequitur. That some regions of space exist solely in our minds does not imply the same for all spatial properties.

Again, decoherence being an important step in the Aristotelian argument for the legitimacy of treating the positions of macroscopic objects as factual per se, one might conclude that all that is thereby established is the relative and intersubjective reality of the classical domain, and that Aristotelians are therefore crypto-Platonists. But this too is a non sequitur. It would follow if the positions/times on which a wave function depends were the intrinsic positions/times of an intrinsically and infinitely differentiated physical space/time, for then the epistemic nature of wave-function collapses (in the context of unadulterated, standard quantum mechanics) would be beyond question. In this case einselection can at best ensure the macroscopic predictability of observations. In the Aristotelian theory of decoherence, on the other hand, einselection ensures the macroscopic predictability that is a necessary condition for the attribution of factuality. The reality established by the Aristotelians, therefore, is the observer-independent reality of facts, of
properties whose possession is indicated by facts, of the positions of macroscopic objects that ultimately constitute the facts, and of the statistical correlations that obtain among property-indicating facts.

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