MAKING SENSE OF A WORLD OF CLICKS

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In a recent article O. Ulfbeck and A. Bohr (Foundations of Physics 31, 757, 2001) have stressed the genuine fortuitousness of detector clicks, which has also been pointed out, in different terms, by the present author (American Journal of Physics 68, 728, 2000). In spite of this basic agreement, the present article raises objections to the presuppositions and conclusions of Ulfbeck and Bohr, in particular their rejection of the terminology of indefinite variables, their identification of reality with “the world of experience,” their identification of experience with what takes place “on the spacetime scene,” and the claim that their interpretation of quantum mechanics is “entirely liberated” from classical notions. An alternative way of making sense of a world of uncaused clicks is presented. This does not invoke experience but deals with a free-standing reality, is not fettered by classical conceptions of space and time but introduces adequate ways of thinking about the spatiotemporal aspects of the quantum world, and does not reject indefinite variables but clarifies the implications of their existence.

1 INTRODUCTION

In a recent article O. Ulfbeck and A. Bohr [1] have pointed out certain features of quantum mechanics (QM) the significance of which has not been sufficiently appreciated. Foremost among these is the genuine fortuitousness of detector clicks, which are usually thought of as being caused (“triggered”) by the impact of a particle: “the individual fortuitous event, which quantum mechanics deals with, comes by itself, without any cause, and is entirely beyond theoretical analysis.” (Quotations without reference numbers are from Ref. 1.)

The idea that a detector click is “a totally lawless event” is not entirely unheard-of. In a letter to Max Born, Wolfgang Pauli spoke of the “appearance of a definite position $x_0$ during an observation...as a creation existing outside the laws of nature” [2]. More recently the present author has argued that a value-indicating event such as the click of a detector is what philosophers call a causal primary—it occurs without a cause and is therefore fundamentally inexplicable [3].
According to Ulfbeck and Bohr, QM is exclusively concerned with distributions of clicks: “The wave function enters in the sole role of encoding the probability distributions of clicks.” This view is close to the “correlation interpretation” \[4\], a common ground that ought to be acceptable to everyone, inasmuch as within its minimal conceptual framework “no conflict of postulates takes place” \[4\]. What divides the physics community is the attempt to go beyond the correlations and say something reasonable about the correlata and their relation to the correlations. I fully agree with Ulfbeck and Bohr that such an attempt ought to take due account of the genuine fortuitousness of the correlata. This constraint, however, leaves plenty of room for disagreement, as will become obvious in what follows.

2 WHY FORTUITOUS?

My first dissent concerns the reason why the correlata are uncaused. Ulfbeck and Bohr aim to establish the genuine fortuitousness of detector clicks by pointing to the immense complexity and consequent uniqueness of each “macroclick,” when this is seen in sufficiently high resolution: “the click involves such an immense number of degrees of freedom that two clicks are never identical. . . . Laws for clicks arise when the click . . . is seen with a lowered resolution . . . . With the lowered resolution, clicks can repeat thereby defining probability distributions that are within the domain of law.” What is actually addressed here is the measurability of probabilities in terms of relative frequencies. The probability of a unique event cannot be measured. QM, however, assigns probabilities regardless of whether they can be measured.

That the above argument is irrelevant to the genuine fortuitousness of detector clicks is also obvious from the authors’ independent insistence that the onset of a click, “from which the click evolves as a signal in the counter . . . . does not belong to a chain of causal events” and “is not the effect of something.” As I see it, the reason for this is that the probability that a variable $Q$ has the value $v$ is the product of two probabilities—the probability that any one of the possible values of $Q$ is indicated, and the probability that the indicated value is $v$ given that a value is indicated. QM is exclusively concerned with probabilities of the latter type. It does not assign a probability to the occurrence of a value-indicating event, nor does it specify sufficient conditions for such an event. If QM is a fundamental and universal theoretical framework, this means that the value-indicating events presupposed by QM are uncaused.

3 INDEFINITENESS

My second and perhaps chief dissent concerns the authors’ rejection of the terminology of indeterminate variables. There is no doubt that this terminology is potentially confusing, but given the obvious importance of the indefiniteness or relative positions for
the existence of spatially extended material objects \[5\], what is needed is not a wholesale rejection but a conceptual clarification.

The proper way of dealing with indefinite values is to make counterfactual probability assignments \[3, 6\]. If we say that a variable has an “indefinite value,” what we mean is that it does not have a value (inasmuch as no value is indicated) but that it would have a value if one were indicated, and that positive probabilities are associated with at least two possible values. (While the reference to counterfactuality cannot be eliminated, it may be shifted from values that are only counterfactually indicated to values that are only counterfactually indefinite: If a certain measurement is performed on an ensemble of identically “prepared” systems and the results exhibit a positive dispersion, the value of the measured variable would be indefinite for each system if the measurement were not performed.)

If a variable sometimes does and sometimes does not have a value, a criterion is called for, and this is the existence of a value-indicating fact. In other words, the matrix variables of QM are *extrinsic*, in the sense that each possesses a value only if, and to the extent that, a value is indicated (by an actual event or state of affairs).

Ulfbeck and Bohr object to such statements as the following, which they find “difficult to fathom”: The spin-component of an electron has two possible values, yet it lacks an actual value; the neutron traverses the interferometer, yet it does not pass through a particular arm of the interferometer. Given the extrinsic nature of the matrix variables, the meaning of these statements ought to be clear. If something indicates the value of a particular spin component, it indicates either of two possible values, and the indicated value is possessed at the time of indication; if nothing indicates a value for a given time, no value is possessed at that time. By the same token, if the neutron’s passage through the interferometer can be inferred from the facts then the neutron did traverse the interferometer, and if nothing indicates the arm taken by the neutron then the neutron did not pass through a particular arm. If this last statement is still difficult to fathom, it is because we approach the quantum world with an inadequate concept of space (Secs. 5 and 7).

The authors for their part make statements that others may find difficult to fathom: “a matrix variable manifests itself on the spacetime scene, without entering this scene”; “the clicks can be classified as electron clicks, neutron clicks, etc., although there are no electrons and neutrons on the spacetime scene”; “[s]omething has happened to the source” yet “no events have taken place in the source.”

These statements, too, cease to be obscure when the extrinsic nature of matrix variables is taken into account. The authors make a sharp distinction between the matrix variables of the theory and what takes place in spacetime or is present on the spacetime scene. On the spacetime scene we have events such as the clicks, involving material objects such as counters, and “all physical phenomena including clicks are described in terms of variables that each has a value, at any time.” A matrix variable, on the other hand,
does not have a value under any circumstance.” It never enters the spacetime scene, but it “can manifest itself (appear) with a value.”

The reason why this distinction is justified is that a fundamental physical theory which is essentially a probability algorithm presupposes (i) actual events to which probabilities can be assigned and (ii) actual events or states of affairs on the basis of which probabilities can be assigned. These events or states of affairs are described in terms of intrinsic variables—variables that possess values at all times. That a matrix variable never has a value and never enters the spacetime scene is a way of saying that it is not an intrinsic variable: It never has a value by itself. Correspondingly, that a matrix variable can manifest itself on the spacetime scene with this or that value is a way of saying that it is an extrinsic variable: It has a value only if, and to the extent that, a value is indicated.

Suppose that we perform a series of position measurements, and that every measurement yields exactly one result (that is, each time exactly one detector clicks). Then we are entitled to infer the existence of a persistent object, to think of the clicks given off by the detectors as indicating the successive positions of this object, to think of the behavior of the detectors as position measurements, and to think of the detectors as detectors. If instead each time exactly two detectors click (including the possibility that the same detector clicks twice), we are entitled to infer the existence of two objects (but not of two distinct individuals, unless distinguishing properties are also indicated). The upshot is that the number of “components” of a quantum system is as much an extrinsic variable of the system as the positions of its components.

Thus when Ulfbeck and Bohr state that there are no electrons and neutrons on the spacetime scene, I take it to mean that the number of electrons or neutrons present in a system is not an intrinsic variable: It never has a value by itself. It is not the case that electron clicks happen because there are self-existent electrons that occasionally enter electron counters and produce clicks; rather, electrons exist only because each electron click indicates the presence of an electron in a particular region at a particular time. The electron’s presence supervenes on the click. (“Supervenience” is a suitable philosophical term for the relation between extrinsic values and value-indicating facts. The extrinsic values supervene on the value-indicating facts.)

When Ulfbeck and Bohr state that the source ("defined in terms of a distribution of clicks observed, for example, at the boundary of the source") “constitutes an object in space, with non-classical properties that can be established by the observation of distributions of clicks,” the properties they refer to are non-classical in that they are extrinsic. At first sight the authors’ statements that "[s]omething has happened to the source" yet "no events have taken place in the source" seem inconsistent. If due account is taken of the extrinsic nature of those properties, the apparent inconsistency disappears. As the authors themselves explain, “the events that tell us that something has happened to the source... do not take place in the source.” In other words, what happened to the source supervenes on a click that occurs at the boundary of the source. While it is correct
that “nothing takes place in the source that could be a cause of the click in the counter,”
saying that “no events have taken place in the source” is correct only in the sense that
no intrinsic events have taken place there—no event has occurred by itself and triggered
the counter. This does not rule out events in the source that supervene on the clicks at
the boundary of the source.

4 EXPERIENCE AND REALITY

My third objection concerns the reality claims that go with the authors’ distinction be-
tween matrix variables and what is present or takes place on the spacetime scene. Central
to their conceptual scheme is (i) “the identification of reality with the world of experi-
ence” and (ii) “the identification of experience with what takes place on the spacetime
scene.” From these identifications it follows that a matrix variable, which “cannot enter
the spacetime scene,” lacks reality. Ulfbeck and Bohr confirm this when they explain why
they avoid expressions like “the world of matrix variables”: “it might convey the notion
that something exists beyond the world of experience.” At the same time they affirm
that “the matrix variables are physical quantities,” and that they are “variables in their
own right.” These are conflicting claims. How can a physical quantity that is a variable
in its own right not be real?

The authors state that “the locality permeating the quantal formalism is a symbolic
one (which can be expressed in terms of fields that are associated with spacetime points
but are not themselves on the spacetime scene since they derive from matrix variables).”
What can be associated with a spacetime point without being present at that point?
The obvious answer: the probability for something to happen or be present at that
point. Denying reality to a matrix variable comes down to saying that the probability for
something to happen or be present in a given region \( R \) at a given time \( t \) is not something
that exists either in \( R \) or at \( t \). A matrix variable is unreal for the same reason that a
possibility per se is not an actuality, and it can manifest itself on the spacetime scene for
the same reason that something that is possible can be actual as well. There is no need to
support these truisms with (inconsistent) reality claims, let alone to support these reality
claims with metaphysical claims about experience and the spacetime scene.

By definition, empirical science deals with the world of experience. For this reason it
cannot possibly tell us anything about what lies beyond the world of experience. Nor is
experience (in the broadest sense of the term) amenable to empirical investigation since
experience (in this sense) encompasses the world of experience and therefore does not
take place within it. By confining reality to “the world of experience” Ulfbeck and Bohr
make it clear that they refer to experience in this broadest sense, and this makes their
reference to “experience” gratuitous and irrelevant.

Experience becomes accessible to scientific investigation in the attenuated sense of
a relation between one part of the world of experience and another. Psychologists and
neuroscientists have arrived at an impressive understanding of the relation between the “external” world—one part of the world of experience—and its representation in the mind or by the brain—another part of the world of experience,—even though the “final” step to subjectivity remains shrouded in mystery since it concerns the existence of experience in its broadest sense, rather than the relation between one part of the world of experience and another. There is thus considerable a posteriori evidence—at least within psychology—of the usefulness of the division of the world of experience into a physical part—the world “out there” including the scientifically known brain—and a phenomenal part—the world as we perceive it.

I believe that the distinction between the phenomenal world—the world as we perceive it—and the physical world—the world as we theoretically conceive it—is equally useful for elucidating the ontological import of QM. Niels Bohr wrote:

> It is my personal opinion that these [interpretational] difficulties are of such a nature that they hardly allow us to hope that we shall be able, within the world of the atom, to carry through a description in space and time that corresponds to our ordinary sensory perceptions. [7]

Bohr did not say that a spatiotemporal description was impossible but only that such a description could not be modeled after our ordinary sensory perceptions. The distinction between the physical and phenomenal worlds allows us to distinguish between the spatiotemporal features of the phenomenal world, which correspond to our ordinary sensory perceptions, and the spatiotemporal features of the physical world, which don’t. And it may well be that the key to understanding QM lies in the unfamiliar spatiotemporal features of the quantum world—the physical world as described by QM. If so, Ulfbeck and Bohr could be blamed for delaying the progress of science just as Kant has been blamed for having delayed the discovery of non-Euclidean geometries by arguing that the validity of Euclidean geometry was a priori certain [8].

The milestones in the history of science can be characterized by the recognition that what was once unquestioningly accepted—e.g., Euclidean geometry, absolute simultaneity—actually lies within the compass of empirical falsifiability. Ulfbeck and Bohr adhere to the Kantian doctrine that “[s]pace and time constitute a scene established for the ordering of experiences,” according to which spatiotemporal concepts have meaningful application only to what appears on the mental canvas woven out of space and time. In so doing they arbitrarily confine empirical reality to what is accessible to direct sensory experience, and render scientifically unassailable concepts of space and time that corresponds to our ordinary sensory perceptions. Thus, like Kant, they could be accused of delaying an adequate understanding of the spatiotemporal aspects of the physical world, and hence of QM.
Making sense of QM is not so much a question about the ontological status of density operators—they are just sophisticated probability measures—as a question about the ontological status of the space and time coordinates that appear as arguments of density operators in the position representation. The demonstration that these coordinates cannot refer to the self-existent and intrinsically differentiated spatiotemporal background of classical physics requires nothing more elaborate than a two-slit experiment with electrons [9].

No electron is detected in the absence of the electron source in front of the slit plate, and no electron is detected behind the slit plate whenever the two slits are closed. This warrants the inference that each detected electron went through $L$&$R$, the regions defined by the slits considered as one region. At the same time the existence of interference fringes implies that each electron went through $L$&$R$ without going through a particular slit and, of course, without having been split into parts that went through different slits. (Like Ulfbeck and Bohr, I am concerned with the interpretation of standard QM unadulterated with, e.g., Bohmian trajectories [10] or nonlinear modifications of the “dynamics” [11].) But if space were something that existed by itself, independently of its material “content,” and if it were made up of distinct, separate regions, every material object would be affected by this. No material object could be present in $L$&$R$ without either being wholly contained in one of the regions or having a part in each region.

Interference fringes have been observed using $C_{60}$ molecules and a grating with 50-nm-wide slits and a 100-nm period [12]. Do we need any further proof that (in the context of standard QM) $L$ and $R$ cannot be distinct, self-existent “parts of space,” and that, consequently, space cannot be a self-existent and intrinsically partitioned expanse?

Although we readily agree that red, or a smile, cannot exist without a red object or a smiling face, we just as readily believe that positions can exist without being properties of material objects. We are prepared to think of material objects as substances, and we are not prepared to think of their properties as substances—except for their positions. (A substance is anything that can exist without being the property of something else.) There are reasons for these disparate attitudes, but they are psychological and neurobiological. They concern the co-production, by the mind and the brain, of the phenomenal world. They do not apply to the quantum world, but they certainly make it hard to make sense of it [13, 14].

What is ultimately responsible for the disparate ways in which we handle positional information and other sensory data is the process by which the mind/brain integrates into phenomenal objects such phenomenal variables as hue, lightness, shape, and motion. This integration is based on positional information [15]. Phenomenal variables that occur in the same place are perceived as features of the same object, despite being neurally represented in separate feature maps. (A feature map is a layer of the neocortex in which cells map a particular phenomenal variable in such a way that adjacent cells generally
correspond to adjacent locations in the visual field. In the macaque monkey as many as 32 distinct visual feature maps have been identified.) Thus while every phenomenal variable except location has at least one separate map, locations are present in all maps as the integrating factors. This unique role played by positional information in the process of feature integration is one of the reasons why we conceive of space as a pre-existent and intrinsically differentiated expanse. The neural process of feature integration, on which the creation of the phenomenal world is based, can only work if distinct locations somehow pre-exist. The creation of a physical object, on the other hand, is not a process that involves the integration of perceived features, so there is no reason to believe that physical space pre-exists as an intrinsically differentiated expanse. In fact, as the above analysis of an interference experiment has shown, this belief is inconsistent with QM.

In the physical world the so-called “parts of space” are not real and distinct per se. A spatial region has a contingent reality, in the sense that it may exist for one material object and not exist for another. This calls for a criterion, and the obvious criterion is this: A region $V$ is real for an object $O$ if and only if the proposition “$O$ is in $V$”—symbolically, $O \rightarrow V$—has a truth value. And the sufficient and necessary condition for the existence of a truth value is that one is indicated. But the truth or falsity of $O \rightarrow V$—can be indicated only if $V$ exists, and for this is must be realized (made real) by being a possessed position that can be consistently considered intrinsic. This takes us to the genuine core of the so-called measurement problem, whose solution requires a demonstration of the consistent coexistence of extrinsic and intrinsic variables.

6 SOLUTION OF THE MEASUREMENT PROBLEM

There are objects whose indicated positions are so correlated that every one of them is consistent with every prediction that is based on previous indicated positions and a classical law of motion (except, of course, when the indicated positions serve to indicate unpredictable values). If I take this characterization as a definition of “macroscopic object,” I need to show that such objects exist. Note that this definition does not require that the probability of finding a macroscopic object where classically it could not be, is strictly 0. What it requires is that there be no position-indicating fact that is inconsistent with predictions based on a classical law of motion and earlier position-indicating facts.

The departure of an object $O$ from a classical trajectory can be indicated only if there are detectors whose position probability distributions are narrower than $O$’s. Such detectors do not exist for all objects. Some objects have the sharpest positions in existence. For these objects the probability of a position-indicating event that is inconsistent with a classical trajectory is necessarily very low. It is therefore certain that among these objects there will be macroscopic ones.

Since no object has an exact position, it might be argued that even for a macroscopic object $M$ there always exists a small enough region $V$ such that the proposition $M \rightarrow V$
lacks a truth value. But this is an error. Macroscopic objects have the sharpest positions in existence. There isn’t any object that has a sharper position. *A fortiori*, there isn’t any object for which $V$ is real. But a region exists only if it is real for at least one material object. It follows that there exists no region $V$ such that the proposition $M \rightarrow V$ lacks a truth value. Such a region may exist in our imagination, but it does not exist in the real world.

Now recall why positions are extrinsic: The proposition $O \rightarrow V$ may or may not have a truth value. One therefore needs a criterion for the existence of a truth value: A truth value must be indicated. But one doesn’t need a criterion for the existence of a truth value if for every *existing* region $V$ the proposition $M \rightarrow V$ has a truth value. Since macroscopic objects satisfy this condition, their positions can be consistently considered intrinsic. We can think of the positions of macroscopic objects (macroscopic positions, for short) as forming a system of causally connected properties that are effectively (that is, for all quantitative purposes rather than merely all practical ones) detached from the facts by which they are indicated. We can think of this system as a self-existent and self-contained causal nexus interspersed with transitions (of value-indicating positions) that are causally linked to the future but not to the past.

Since the beginning of time (in about 1926) it has been argued that QM is about experience, knowledge, or information [16, 17, 18, 19], rather than about a free-standing reality capable of being described without reference to observers, their information, their interventions into “the course of Nature” [20], or their arbitrary decisions as to where to make the “shifty split” between “system” and “apparatus” [21]. Why? Because it is such an easy way to establish the consistent coexistence of extrinsic and intrinsic variables. If the properties of the quantum world are extrinsic (that is, if they “dangle” from, or supervene on, something), and if the quantum world is coextensive with the physical world, then from what can they “dangle”? The obvious answer: from us, from what we perceive, or from what we know.

For this easy way out we pay a high price. By safeguarding against empirical refutation conceptions of space and time that are consistent with the phenomenal world but inconsistent with the physical world, we make sure that we won’t discover the spatiotemporal features of the quantum world. And by rooting the possible value-indicating events, to which QM assigns probabilities, in the world of sensory experience, we make sure that we can’t conceive of the quantum world as a strongly objective, free-standing reality that owes nothing to observers, information, or our interventions into the course of Nature.

### 7 PHYSICAL SPACE VS PHENOMENAL SPACE—II

Macroscopic positions are so abundantly and so sharply indicated that they are only counterfactually fuzzy. Their fuzziness never evinces itself, through uncaused transitions or in any other manner. It exists solely in relation to an imaginary spatial background
that is more differentiated than the physical world. The space over which the position of a macroscopic object is “smeared out” is never probed. This space is undifferentiated; it contains no smaller regions. We may imagine smaller regions, but they have no counterparts in the physical world. The distinctions we make between them are distinctions that nature does not make.

It follows that the quantum world is only finitely differentiated spacewise, and that it ought to regarded as constructed from the top down, by a finite process of differentiation, rather than from the bottom up, on a self-existent and maximally differentiated spatial expanse. And much the same applies to the world’s temporal aspect. Time is not an independent observable; it has to be read off of deterministically evolving positions—the positions of macroscopic clocks. If these bear a residual fuzziness, so do all indicated times. The upshot: The quantum world is maximally differentiated neither spacewise nor timewise, and it is constructed from the top down with respect to both space and time.

To advance further, we must be clear about what it means when a particle is said to be “pointlike.” This is an expression of the fact that the particle lacks internal structure. Nothing in the formalism of QM refers to the shape of an object that lacks internal structure, and the empirical data cannot possibly do so. All that experiments can reveal in this regard is the absence of evidence of internal structure. The idea that a so-called “point particle” is an object that not only lacks internal relations but also has the shape of a point, is thus unwarranted both theoretically and experimentally. It is, besides, seriously misleading, inasmuch as the image of a pointlike object suggests the existence of an infinitesimal neighborhood in an intrinsically and maximally differentiated spatial expanse. To bring our intuitions in line with the spatiotemporal aspects of the quantum world, we need to conceive of all so-called “point particles” as formless objects. What lacks internal relations also lacks a shape.

It follows that the shapes of material objects resolve themselves into sets of (more or less fuzzy) spatial relations between formless objects, and that space itself is the totality of such relations—relative positions and relative orientations. It further follows that the corresponding relata do not exist in space. Space contains, in the proper, set-theoretic sense of “containment,” the forms of all things that have forms—for forms are sets of spatial relations—but it does not contain material objects over and above their forms; a fortiori it does not contain the formless constituents of matter. Instead, space exists between them; it is spanned by their relations.

The quantum world with its fuzzy spatial relations does not “fit” into the self-existent and maximally differentiated expanse of classical space; the possibility of thinking of the relata as points and embedding them in a single manifold exists only if all spatial relations are definite (“sharp”). A clear distinction should therefore be made between the existing (more or less fuzzy) spatial relations that constitute physical space, and the purely imaginary space that comes with each material object O and contains the unpossessed exact positions relative to O. These imaginary spaces are delocalized relative to each
other: The unpossessed exact positions relative to \( O \) are fuzzy relative to any material object other than \( O \).

The difference between the respective ways in which spatial distinctions are realized in the physical and phenomenal worlds could hardly be greater. In the physical world spatial distinctions are realized by means of (more or less fuzzy) spatial relations between formless objects. In the phenomenal world they are realized by means of boundaries. Visual representations arise by way of an analysis of the visual field that capitalizes on contrast information. Data arriving at the visual cortex from homogeneously colored and evenly lit regions of the visual field do not make it into conscious awareness. Such regions are filled in on the basis of contrast information across their boundaries [14]. (This explains, among many other things, why the blind spot goes unperceived whenever it falls in such a region.) The way in which the brain processes visual information thus guarantees that the result—the phenomenal world—is a world of objects whose shapes are bounding surfaces. The parts of any phenomenal object accordingly are defined by the parts of the space it “occupies,” and these are defined by delimiting and separating surfaces. This too implies that the parts of space pre-exist somehow—otherwise they couldn’t define the parts of a phenomenal object,—and this is another reason why we tend to conceive of space (inconsistently with the quantum world) as a pre-existent and intrinsically differentiated expanse.

8 SUBSTANCE AND THE QUANTUM WORLD

There are other respects in which the physical world is built top-down rather than bottom-up. If all substances were intrinsically distinct, the world could be thought of as constructed from the bottom up, by aggregation. The same would be true in a deterministic world, since determinism allows us to associate a distinct substance with each possessed position.

For centuries philosophers have argued over the existence of intrinsically distinct substances. QM has settled the question for good: There are no intrinsically distinct substances. The concept of substance betokens existence; it never betokens individuality. Individuality is strictly a matter of properties. Given the extrinsic nature of properties, this means that a quantum system can be associated with distinct substances only to the extent that distinguishing properties are indicated. Since this extent is limited, the possibility of decomposing the quantum world into distinct substances is limited as well. Hence the quantum world ought to be regarded as constructed from the top down not only with regard to its spatial and temporal aspects but also with regard to its substantial aspect.

If we believe that QM is about regularities in sensory experience, we don’t need the concept of “substance.” But we need it if we want to think of the quantum world as a free-standing reality, inasmuch as it is the concept of “substance” that betokens independent
existence. And we need to know how the quantum world relates to its substance. Since it would be absurd to substantialize a probability algorithm, substantiality can’t be attached to a state vector or a wave function, as Ulfbeck and Bohr correctly point out. Nor can it be attached to the points of a spacetime manifold, as the previous sections have shown. Nor can the substance of the quantum world be decomposed into a multiplicity of intrinsically distinct substances, as we just saw.

If the property of being here and the property of being there are simultaneously possessed, how many substances does that make? The correct answer is “one,” for the substance that betokens the reality of the property of being here also betokens the reality of the property of being there. QM does not permit us to interpose a multiplicity of distinct substances between the substance that betokens existence and the multiplicity of possessed positions. QM thus lends unstinting support to the constitutive idea of all monistic ontologies: Ultimately there is only one substance. As physicists we are not concerned with the intrinsic nature of this substance. (It arguably plays an important role in the emergence of consciousness). What is of interest to us is how it acquires the aspect of a spatiotemporal expanse teeming with quarks and leptons.

In broad outline the answer is simple enough: By entering into spatial relations with itself, this substance acquires at one stroke the aspect of a multiplicity of spatial relations, which constitute forms and space, and the aspect of a multiplicity of formless relata, which constitute matter. And if we allow the spatial relations to change, we have time as well, for change and time are co-implicates. (In a timeless world nothing can change, and a world in which nothing changes is a world without temporal relations; such a world is temporally undifferentiated and therefore timeless, just as a world without spatial relations is spatially undifferentiated and therefore spaceless.)

9 WHAT HAPPENS BETWEEN VALUE-INDICATING FACTS?

What can be said about the interval between two times for which properties are indicated if no property is indicated for any intermediate time? To begin with, consider again a two-slit experiment in which all that is indicated is each electron’s place of departure in front of the slit plate and its place of arrival behind the slit plate. While the propositions \( e \rightarrow L \) ("the electron went through \( L \)") and \( e \rightarrow R \) lack truth values, the corresponding histories contribute to the observed probability distribution. We therefore have reason to conclude that both histories happen, but indistinguishably, in the sense that the distinction we make between them is a distinction that nature does not make. The reason why we cannot assign separate truth values to \( e \rightarrow L \) and \( e \rightarrow R \) but only a single truth value to \( e \rightarrow L \& R \) is that the conceptual difference between the two histories has no counterpart in the physical world.

The probability of detecting at a given time and location a particle having last been
“seen” at another time and location, is determined by a “propagator” \( K(x_2, t_2; x_1, t_1) \) that can be calculated by summing over all continuous paths leading from \((x_1, t_1)\) to \((x_2, t_2)\) \[22, 23\]. Hence nothing stands in the way of the claim that if the particle is present at these two spacetime locations, and if nothing indicates its intermediate whereabouts, then it does travel along all of those paths, subject to the understanding that the distinctions we make between these histories correspond to nothing in the physical world.

If the initial and final states of affairs include indistinguishable particles, there are further distinctions that nature does not make. The distinctions we make between histories that connect particular incoming particles with particular outgoing particles of the same type, which are based on the false notion that particles are intrinsically distinct substances, also correspond to nothing in the physical world. Such histories happen together, indistinguishably, in the sense spelled out above. Finally, if the possibility of pair events is taken into account, the histories that happen together, indistinguishably, are constrained only by conservation laws. In general it can be said that whenever QM requires the addition of amplitudes, the distinction we make between the corresponding histories do not exist in the physical world.

It is obvious that this interpretation crucially depends on the extrinsic nature of quantum variables. It is clearly impossible to construe a sum over histories leading from one state of affairs to another as something that happens “by itself,” rather than as something that supervenes on these states of affairs. It is not the case that an electron is detected by a detector because it followed all continuous paths leading from the source to the detector. Rather, the electron followed all these paths because it left the source and was detected by the detector, and because there are no matters of fact about its intermediate whereabouts.

Every value-indicating fact realizes the difference between a range of possible values, inasmuch as what is indicated is not only the possession of a particular value (the truth of one proposition) but also the non-possession of all other possible values (the falsity of \(n-1\) propositions, \(n\) being the number of possible values). (Recall that our distinctions between alternatives correspond to something in the physical world if and only if truth values are indicated for the corresponding propositions.) Every value-indicating fact therefore reduces the set of histories that happen indistinguishably. Hence in a sense the world is built top-down also dynamically: from “everything at once” to something specific, by an elimination of alternatives. Every value-indicating fact reduces the set of histories that happen together, yet even the totality of value-indicating facts does not reduce it to a single history.

\section*{10 Conclusion}

The metaphysical presuppositions of Ulfbeck and Bohr effectively safeguard against empirical refutation conceptions of space and time that are essentially classical. Claims by
these authors to the effect that genuine fortuitousness “does not invoke notions taken over from classical physics,” and that matrix variables are “entirely liberated” from such notions, must therefore be taken with a grain of salt.

An alternative view of QM has been presented, which is liberated from such notions to an extent that permits conceiving of the quantum world as a free-standing reality. Central to this view is a conceptual clarification of the indefiniteness that is crucial for the stability of spatially extended material objects. This requires novel conceptions of space and time, and it implies a top-down structure for the quantum world: Rather than being built bottom-up, on a maximally differentiated spatiotemporal manifold, the quantum world arises from a limited spatiotemporal differentiation. A similar top-down structure characterizes its substantial and dynamical aspects.

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