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## 2. RANDOMNESS FROM RELATIONSHIPS AND INTERFACES<sup>1</sup>

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**In :** Anne Duprat and Alison James (eds.), *Figures of Chance II. Chance in Theory and Practice*, Routledge, 2024

### Introduction

The most appropriate way of conceiving quantum indeterminacy is akin to a “middle way”. Quantum indeterminacy is neither the reflection of the chaos of a universe separated from us, nor the expression of our partial ignorance of nature. It arises from the inseparability of a phenomenon from the conditions in which it manifests itself. In other words, quantum indeterminacy is *essentially correlational*.

To convince ourselves of this, we must return to quantum theory itself. This theory can largely be derived from a hypothesis of dependency of its typical determinations with regard to an experimental context<sup>2</sup>. Or, if one prefers, it can be derived from the hypothesis that each phenomenon is an instantaneous creation<sup>3</sup> rather than a “manifestation” of some pre-existent property. Quantum theory becomes more easily intelligible, and devoid of paradoxes, once we stop referring to the putative intrinsic determinations of objects.

Basically, to clarify the meaning of quantum theory<sup>4</sup> it is enough to stop seeing it as a description of a pre-existent state of things, but instead as a way of predicting phenomena whose conditions of occurrence hinge on future choices<sup>5</sup>. Abandoning the idea that scientific theories describe a world which is deemed to be independent of experience and action, and instead considering that they predict *correlates of our action and experience*, immediately gives them back a meaning that they had lost and that no attempt at restoring their realistic interpretation

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<sup>1</sup> Preliminary research on this subject has been presented in M. Bitbol, “L’indéterminisme entre deux infinis : absence de causes ou excès non-maîtrisable de conditions”, in: P. Bourguine, D. Chavalarias and C. Cohen-Boulakia (eds.), *Déterminismes et complexités : du physique à l'éthique. Autour d'Henri Atlan*, Éditions La Découverte, 2008.

<sup>2</sup> J.-L. Destouches, *Principes fondamentaux de physique théorique*, Hermann, 1943 ; R.I.G. Hughes, *The Structure and Interpretation of Quantum Mechanics*, Harvard University Press, 1992; M. Bitbol, *Mécanique quantique, une introduction philosophique*, Champs-Flammarion, 1997. See also the many “informal” derivations of quantum mechanics. A. Grinbaum, “Reconstruction of quantum theory”, *British Journal for the Philosophy of Science*, 58, 387-408, 2007; G.M. D’Ariano, G. Chiribella and P. Perinotti, *Quantum Theory from First Principles*, Cambridge University Press, 2017.

<sup>3</sup> C. Fuchs, “On participatory realism”, arXiv:1601.04360v3 [quant-ph] 2016

<sup>4</sup> M. Bitbol, “Quantum mechanics as generalized theory of probability”, *Collapse*, 8, 87-121, 2014; I. Pitowsky, “Quantum mechanics as a theory of probability”, in: W. Demopoulos & I. Pitowsky I. (eds), *Physical Theory and its Interpretation*, The Western Ontario Series in Philosophy of Science, vol 72, Springer, 2006; J. Bub, *Bananaworld: Quantum Mechanics for Primates*, Oxford University Press, 2016.

<sup>5</sup> C. Fuchs & R. Schack, “QBism and the Greeks: why a quantum state does not represent an element of physical reality”, *Physica Scripta*, 90, 015104, 2015.

had been able to give them. Quantum theory in its entirety might accurately be termed a “general theory of correlational prediction”.

## **2.1 Quantum theory as an archetypal counter-example of the critique of “correlationism”**

The fact this “middle way”, this in-between approach that is neither “natural” nor “subjective” is the best way of clarifying quantum indeterminacy, cannot be without consequence for the contemporary metaphysical debate. It is an indication of the fertility and generality of what the defenders of a variety of “speculative realism”<sup>6</sup> have denounced under the name of “correlationist” epistemology<sup>7</sup>. Conversely, it suggests the inadequacy of the idea of revealing an absolute, an “in-itselfness”, that this strand of philosophy supports.

There are thus good reasons to think that the supporters of speculative realism are mistaken when they think they can base their ideas on a defence and illustration of the usual scientific description of nature. While it is true that realistic epistemology bears out the spontaneous philosophy of most scientific researchers<sup>8</sup>, thus lending some credibility to their ontological engagement with a set of entities and past events, it generates a profound misunderstanding of the meaning of the most advanced scientific theories, especially in contemporary physics. This meaning, revealed by carefully studying the history of physics, is in complete accordance with the correlationist epistemology against which speculative materialism has developed. It arises from a periodical expansion of the field of application of *principles of relativity*, and from the systematic replacement of entities or properties from a previous phase with trans-relational invariants belonging to a later stage of the development of physics<sup>9</sup>.

In other words, although it grates with researchers eager to produce “absolutist” *discourse*, correlationist epistemology fully embraces their “relativist” *activity* and clarifies its epistemological implications. On the contrary, although the epistemology of speculative materialism rescues the dream of ontological literalness that motivates the vocation and

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<sup>6</sup> T. Sparrow, *The End of Phenomenology: Metaphysics and the New Realism*, Edinburgh University Press, 2014; P. Gratton, *Speculative Realism, Problems and Prospects*, Bloomsbury Academics, 2014; G. Harman, *Quentin Meillassoux, Philosophy in the Making*, Edinburgh University Press, 2011.

<sup>7</sup> Q. Meillassoux, *Après la finitude*, Éditions du Seuil, 2006.

<sup>8</sup> L. Althusser, *Philosophie et philosophie spontanée des savants*, Maspero, 1974.

<sup>9</sup> E. Cassirer, *La théorie de la relativité d’Einstein*, Editions du Cerf, 2000; M. Bitbol, J. Petitot & P. Kerszberg (eds.), *Constituting Objectivity: Transcendental Perspectives On Modern Physics*, Springer, 2009.

discourse of many researchers, it makes the actual workings of their most advanced theoretical structures illegible or paradoxical.

This general lesson learned from the reflexive analysis of quantum mechanics applies in particular to the much-debated question of quantum indeterminacy. The “general theory of correlational prediction” can only concern events whose indeterminacy is itself correlational. Quantum indeterminacy, as we will show in detail below, results from the impossibility of entirely controlling the conditions in which a phenomenon appears *when you are yourself part of those conditions*. This means that, although some have been tempted to find in quantum indeterminacy a confirmation of the theory of an absolute that “destroys all order”<sup>10</sup>, which has been supported by speculative materialism, it is easy to prove them wrong. Let’s see why.

## 2.2 Is “hyperchaos” absolute or relative?

The ultimate Absolute of the speculative materialist is called “hyperchaos”. It must not, however, be confused with the hyperchaos of complexity theory. The latter goes beyond standard chaos, which appears in a dynamic when infinitely close trajectories diverge at a speed set by a “Lyapunov exponent”, insofar as it implements *two* of these exponents, rather than one<sup>11</sup>. Instead, the hyper-chaos of speculative materialism is “an extreme form of chaos (...) for which nothing is, or seems to be, impossible, not even the unthinkable”<sup>12</sup>. The speculative materialist identifies this Absolute, which he thinks he has attained at the end of his quest, in the very reasoning carried out by his correlationist opponent in order to deny it. So what is this reasoning?

To support his thesis, the correlationist uses a *reductio ad absurdum* initially formulated by Berkeley<sup>13</sup>. Let’s suppose, says Berkeley, that we can think of something independent from thought<sup>14</sup>; that something has thereby become dependent on thought. The correlationist infers that nothing is thinkable *in itself*, but only *relatively to ourselves*.

But wait, replies the speculative materialist: the mere fact of representing a *difference* between what is in-itself and what is relative to ourselves presupposes extracting ourselves, *via* thought, from the “relative-to-ourselves”<sup>15</sup> and thus to allow for the possibility of other relationships with the “in-itself” than those we have actually established. Only this panoramic

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<sup>10</sup> Q. Meillassoux, *Après la finitude*, op. cit., p. 87

<sup>11</sup> O. RöSSLer, “An equation for hyperchaos”, *Physics Letters A*, 71, 155-157, 1979

<sup>12</sup> Q. Meillassoux, *Après la finitude*, op. cit., p. 87

<sup>13</sup> G. Berkeley, *Principles of Human Knowledge* §23

<sup>14</sup> This presentation of the reasoning of the speculative materialist is taken from: M. Bitbol, *Maintenant la finitude*, Flammarion, 2019, Introduction.

<sup>15</sup> Q. Meillassoux, *Après la finitude*, op. cit., p. 80

perspective set up by intelligence can highlight the correlation (the relationship-with-us) in contrast to what lies outside it. If we strictly adhered to the current correlation, how could we distinguish it from a simple manifestation of things themselves? If we were so well immersed in appearance that there was no possibility of perceiving it as a *mere apparition*, how could we justify saying that what presents itself to us *only* pertains to their appearance and *not* to their being? The speculative materialist then observes that there is at least one thing that avoids the trap laid by his correlationist opponent: namely, the latter's ability to think that there *might* be correlations other than this one, or no correlations at all. The very act of denying the independence of anything with respect to thought thus presupposes the "ability of all things to be something else"<sup>16</sup>: the fundamental contingency of what there is. This, according to the speculative materialist, is the only absolute necessity of the world *as it is in itself*. The only "law" that remains, the only absolute nature of what there is, can only be that of *hyperchaos*: the contingency of all the constraining laws discovered by the natural sciences, and thus the constant possibility that these laws might change from one moment to the next. An obvious (but tacit) flaw in this reasoning, which I discuss in chapter 3 of my book *Maintenant la finitude*, is that this conclusion is in turn a thought belonging to the speculative materialist, a thought forgotten by the thinker to make way for his grandiose view of an Absolute independent from the act of thinking. The speculative materialist's Absolute invalidates itself due to its having been *silently* thought by him. Another flaw that is perhaps less visible but which is crucial in the framework of this research in the field of quantum randomness is that the speculative materialist attributes his hyperchaos to "nature-in-itself" alone, whereas the elenctic reasoning that led him to his conviction arises from the need for a correlationist the *think* the "ability-to-be-otherwise" of things, *in the very act of defending her thesis*. Can hyperchaos really be rendered independent of the series of acts of thought and knowledge that have led the correlationist to establish it implicitly, and have subsequently led the speculative materialist to flush it out? Does hyperchaos characterise the "external world" or even the thing-in-itself, as the speculative materialist contends, or does it only concern the phenomenon that emerges during the epistemic activity of an agent-and-thinker-in-the-world? A possible positive response to the latter part of this question opens the way for a correction of the metaphysical thesis of speculative materialism *via* the lesson we learn from quantum physics.

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<sup>16</sup> Q. Meillassoux, *Après la finitude*, Éditions du Seuil, 2006, p. 75

### 2.3 Is quantum randomness a fact of nature?

In the history of quantum physics, three possible meanings of its fundamental use of probability, and of the indeterminacy it presupposes, have been envisaged one by one. The random nature of a process can be a constitutive feature of the nature being explored; it may denote a gap in the knowledge of the researcher exploring it; or it may emerge from the very flow of the activity of exploration. This trio of options extends to three names given to the famous Heisenberg inequalities: equations of indeterminacy (of nature); principle of uncertainty (of the knowing subject); and principle of unpredictability (of phenomena ready to emerge at the interface between nature and the knowing subject).

The first two options have, however, been challenged, not to say formally rejected, in the history of quantum physics.

The idea the indeterminacy belongs to nature “in itself” was suggested by Paul Dirac in the crucial year 1927 when the “Copenhagen” interpretation of quantum mechanics was outlined. Dirac attempted to make sense of the abrupt shift of every quantum “system” from a superposed state to the precise state observed at the end of the process<sup>17</sup>. According to him, this shift from a superposition to a precise state is a “choice of nature” which, “(...) once made is irrevocable and will affect the entire future state of the world”. As this “choice” is random, it can only mean one thing: that the very laws that govern the evolution of natural processes are indeterminist. But Werner Heisenberg didn’t agree. His now famous reply was: “I should rather say (...) that the observer himself makes the choice, because it is only at the moment when the observation is made that the ‘choice’ has become a physical reality and that the phase relationship in the waves, the power of interference, is destroyed”. Heisenberg formally contradicted Dirac by pointing to the act of observation, not nature, as the source of quantum indeterminacy. It was a powerful argument: the effects of interference that result from quantum superposition are maintained throughout the process being studied and only end when the observation is finished. It is thus observation alone that makes the quantum “system” randomly switch from a superposition to one of the precise available states.

The contemporary notion of *decoherence*, which makes the effects of interference negligible for processes whose scale and complexity are sufficient, irrespectively of whether they are part of an observation project or not, does not really weaken Heisenberg’s thesis.

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<sup>17</sup> H.A. Lorentz (ed.), *Électrons et photons. Rapports et discussions du cinquième Conseil de physique tenu à Bruxelles du 24 au 29 octobre 1927 sous les auspices de l’Institut international de physique Solvay*, Gauthier-Villars, 1928 ; G. Bacciagaluppi & A. Valentini, *Quantum Theory at the crossroads: reconsidering the 1927 Solvay conference*, Cambridge University Press, 2009.

Decoherence is fundamentally a deterministic process governed by Schrödinger's equation. The only indeterminate moment is when one of the superposed terms is selected to the detriment of all the other possible ones, and that only happens at the moment an observation is made. The first thesis, that of "natural" indeterminacy, is thus to say the least less than reliable in the field of quantum theory; and it tends irresistibly to be absorbed by the attractor of the third thesis: that of the indeterminacy of the observational interface.

## 2.4 Is quantum randomness subjective?

The second thesis, which states that quantum indeterminacy is only apparent and subjective due to our partial *ignorance* of the "real" laws of nature which are (allegedly) deterministic, is no better founded than the first. The idea that an *apparent* quantum indeterminacy could well be underpinned by deeper deterministic laws was attractive to Einstein, was precisely articulated by Louis de Broglie<sup>18</sup>, and was formalised in David Bohm's first deterministic non-local hidden variable theory<sup>19</sup>. According to de Broglie, each quantum particle is immersed in what he calls a sub-quantum medium comparable to a gas governed by standard statistical mechanics. The erratic collisions between elements in the sub-quantum medium and quantum particles are enough to account for the random movement of the latter, even when *all* the individual processes, be they sub-quantum or quantum, are deemed to be governed by the laws of deterministic mechanics. David Bohm, for his part, explains the apparent indeterminacy of quantum processes by articulating a strictly deterministic evolution and random initial conditions.

We are thus provided with two demonstrations of the fact that the indeterminacy of quantum processes *can* just be a superficial appearance concealing an underlying deterministic reality. The problem is that this demonstration of what can be is in no way equivalent to a demonstration of what must be (of a necessity). As Bohm later showed<sup>20</sup>, whether "real" underlying processes are governed by deterministic or non-deterministic laws, nothing changes at the quantum level. Quantum phenomena are actually indifferent to postulates about the deterministic or non-deterministic nature of an underlying reality. The indeterminacy of quantum phenomena is not enough to prove any thesis about the determinism or indeterminism

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<sup>18</sup> L. de Broglie, *La thermodynamique de la particule isolée*, Gauthier-Villars, 1964.

<sup>19</sup> D. Bohm, "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables", *Physical Review*, 85, 166-179.

<sup>20</sup> D. Bohm and B. Hiley, *Undivided Universe: an Ontological Interpretation of Quantum Theory*, Routledge, 1993.

that prevails in a hypothetical “independent reality”. The indeterminacy of quantum phenomena does not support the doctrine of the hyperchaotic absolute any more than it supports other doctrines.

In any case, the idea of contingent ignorance, in the sense of incomplete knowledge of a field whose deterministic laws *could in principle* be known, is incompatible with the structure of the probabilities that quantum theory makes it possible to calculate. Probabilities relating to events of which we are contingently ignorant would have the additive structure of the standard Kolmogorov theorem. But as we have seen, quantum probabilities don’t add up but *interfere* (like waves). The idea of contingent ignorance of the events predicted by quantum theory is thus automatically invalidated by the very structure of those predictions.

## **2.5 A first approach to “interface randomness”: the “necessary ignorance” argument**

This leaves the third option: that the origin of quantum indeterminacy is as far removed from the hyperchaotic absolute as it is from the contingent ignorance of a deterministic absolute. It is the idea of a hybrid form of randomness: neither intrinsic randomness of some absolute reality, nor randomness superficially generated by of contingent ignorance. In other words, it is the idea that quantum indeterminacy emerges from a relational process that involves the thinker-scientist-agent, immersed in an environment of which she partake. This third option can at the very least be taken as a neutral term compatible with the other two options, which are more metaphysically committed. But it can also be completely detached from the other two options and underpin a metaphysical thesis in its own right: that of the indivisible nature of the world, of its complete un-analysability as a “knowing” pole and a “known” pole.

Even in the latter case, however, the way the third option is formulated incorporates representations and vocabulary from the other two. Interface indeterminacy, indeterminacy of interaction, of correlation, can indeed be expressed either epistemologically or ontologically. It can be seen as expressing a kind of randomness arising from necessary ignorance (as opposed to contingent ignorance, which has been rejected), or as an essentially correlational form of randomness (as opposed to randomness relating to the essence of absolute reality, which cannot be demonstrated). For necessary ignorance is ignorance of an interactive process in which the knowing subject cannot remove herself from it, while essential correlation is that of an interaction in flux in which we cannot tell what belongs to one correlated term or the other.

Let’s begin, then, with the *epistemological* expression of the concept of interface indeterminacy. Henri Atlan formulated it concisely in *Étincelles de hasard*, 2, via the option of



a form of randomness driven by *necessary* ignorance. “What the recognition of quantum indeterminacy contributes to microphysics”, he writes, “is not ‘proof’ of essential or ontological chance in nature, but the acceptance of an absolutely impassable limit, not only practical but theoretical, to the knowledge of what would be an unobservable reality ‘in itself’. The randomness of quantum events is thus imposed by the bounds of knowledge, just as for the standard form of ignorance-driven randomness, except that here the boundary is uncrossable not only *in fact* but *in principle*. To repeat, unlike the boundary of knowledge concerning microscopic processes, which is the basis of standard statistical physics, the boundary of the knowledge of quantum events is a boundary *in principle*<sup>21</sup>.

## 2.6 How can ignorance become necessary?

Of course, to convince ourselves that this boundary imposed on knowledge is uncrossable “in principle” and not just “in fact”, we have to *explain* why it can’t be crossed. If we adopt a Kantian philosophical framework, the explanation is simple. In Kant’s transcendental theory of knowledge, objects are *defined* as phenomena, in other words as products of the correlation between the hypothetical thing-in-itself and the faculty of knowing. If this is so, it is obvious, by definition, that the scientific knowledge of *objects* cannot provide access to some “thing” supposed to exist beyond phenomena, but only to the reaction it causes when it is called upon by the faculty of knowing. Kant admits that we are irresistibly drawn to ask questions about the thing in itself because our reason struggles to accept its own limitations and even because it needs to act *as if* it could go beyond them. But this impulse on the part of reason to imagine something beyond phenomena is (and has to be) subordinated to the epistemological weighting of understanding, which is a simple organiser of phenomena. According to Jaakko Hintikka, this is indeed the case for Kant, because even his concept of the thing-in-itself (which seems, in its very formulation, to overstep the limit of the phenomenon) is actually only a metaphorical expression of that limit. Hintikka considers that, talking about the unknowable thing-in-itself is just a figurative way of admitting that, in a phenomenon, it is impossible to carry out a process of disentanglement that would indicate which aspects of it are due to the environment that knowledge is exploring, and show which aspects relate to our means of knowing.

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<sup>21</sup> This epistemological presentation of “interface randomness” is partly taken from: M. Bitbol, “L’indéterminisme entre deux infinis : absence de causes ou excès non-maîtrisable de conditions”, in: P. Bourguin, D. Chavalarias et C. Cohen-Boulakia (eds.), *Déterminismes et complexités : du physique à l’éthique. Autour d’Henri Atlan*, Éditions La découverte, 2008.

This reference to Kant's theory of knowledge would, of course, be rejected by speculative materialism as an archetypal example of the "correlationist" approach. This rejection would be reinforced by calling out the claim to literal, ontological truth, able to reveal the thing-in-itself, assigned to scientific discourse. The problem (for speculative materialism) is that scientific discourse is underpinned by rigorous scientific research that belies that claim and radicalises, rather than denies, the Kantian boundary of knowledge.

Quantum physics is the pillar on which this denial and the radicalisation of the Kantian boundary stand. In quantum physics, as in Hintikka's take on Kant, it's impossible to distinguish what belongs to the investigative instrument and what belongs to the field being investigated. Better still, the array of quantum phenomena does not even allow itself to be organised in such a way that it would *look as if* they revealed the properties of things-in-themselves. For a temporal sequence of phenomena to express successive aspects of a property intrinsic to a particular object, the phenomena in that sequence would have to be reproduced identically irrespective of the order in which they are observed. And this is not what happens. A fundamental axiom in the first version of quantum theory is the non-commutativity of observables. The corroborated predictions of quantum theory are thus conditioned by the irreducible dependence of phenomena on the order in which they are observed. Correlation is part and parcel of the very mathematical structure of quantum theory. It is this unsurpassable correlation, embedded in the formalism of quantum mechanics, whose demonstrable consequence is the indeterminacy of the phenomena it describes.

## **2.7 Interface: epistemic formulation**

The conclusion we've just drawn about randomness arising from "necessary ignorance" in quantum physics was already suggested by the meticulous examination of what was thought to be "contingent ignorance" in classical physics. I'll illustrate this with a famous study of the origins of randomness carried out by Henri Poincaré. This great French mathematician constantly pointed out our insurmountable ignorance of the determinant causes of physical phenomena, supposing they exist. So much so that this ignorance that was contingent *in principle* becomes necessary *in fact*.

Basically, it could be said that Poincaré leaned asymptotically towards a concept of necessary ignorance but refused to assume its ultimate consequences. If he was inclined to treat our ignorance of determining causes as necessary, it was because of three supposed excesses inherent in these causes with respect to what it is possible for us to know about them. The causes

were, he contended, too small, too complex and too spread out in space to be exhaustively knowable.

First, their smallness: “a very small cause that escapes our notice determines a considerable effect that we cannot fail to see, and then we say that this effect is due to chance”. Second, their complexity: “we attribute [the unexpected occurrence of a meteorological event] to chance because its causes are too complicated and numerous”. Third, their spatial extension: “when we try to foresee a fact and examine its antecedents, we tend to inquire about the previous situation; but we cannot do this for all parts of the universe [...]. It may happen that we have left out circumstances which, at first sight, seemed completely unrelated to the anticipated fact, [...] and which, however, against all predictions, come to play an important role”<sup>22</sup>. These three excesses of the determining causes of events converge and cooperate. The vastness of the universe Poincaré talks about in the third excess only matters if massive effects can result from small causes making their influence felt from a great distance, and if this weak influence is somehow amplified by the complex system affected by the cause.

But can we really say that ignorance of triply excessive causes is *necessary*, beyond its being in principle contingent? Poincaré hesitated to answer this question.

On the one hand, highlighting the three excesses led him to conclude that, if we do not know the determining causes of events, it’s because they are permanently inaccessible to a finite being. This is what gives our ignorance its horizon of necessity. The fact that it’s impossible to know about the entire array of tiny, complex and distant causes, able to alter the initial conditions that must be presupposed in order to apply a deterministic equation (such as the Navier-Stokes equations in hydrodynamics or the Maxwell equations in electromagnetism), has a consequence similar to the one we would expect from *non-deterministic* physics. In the absence of sufficiently precise knowledge of initial conditions, the predictions provided by a law of change either cannot be formulated because of lack of information or are *only probable* despite the formally deterministic nature of the law.

On the other hand, Poincaré persisted in his deterministic profession of faith, which he shared with almost all researchers in the pre-quantum era. He clung to this idea of “determinism-in-principle” because he refused to definitively establish the *degree* to which our knowledge of causal antecedents is limited. According to him, believing in determinism means opening the way to indefinitely increasing our knowledge of the initial conditions of a process

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<sup>22</sup> Poincaré H. (1999), *Science et méthode*, Kimé, Paris, Livre I, §4

in future, even if we must admit that this knowledge can never be exhaustive. This is what justifies calling his brand of determinism “asymptotic” and his concept of ignorance-driven randomness “asymptotically contingent” (but necessary *in fact*).

## 2.8 Interface: ontological formulation

Let’s now move on to the ontological formulation of the idea of hybrid, interfacial randomness. Let’s see how we can *represent* the idea of quantum indeterminacy arising from the *correlation* of the experimenting agent with the environment they are studying, rather than the intrinsic ignorance of the former or the intrinsically chaotic nature of the latter. The idea can be formulated in ontological terms by representing the knower as entirely encapsulated by the known: a participation of the knower in the known that is so tight that any attempt to predict the future of the known independently of the act of knowing, and independently of the very effort of prediction, would be vain. Here, the indeterminacy arises from the fact that the predictor and the predicted cannot be disentangled. If you admit that, as the predictor, you can only be tightly bound up in the process you’re trying to study, it would not make sense for you to represent the causes of the process from a position of exile. For you partake of the causes, and you cannot be exiled from yourself. The only easy fix open to you is to *imagine why it is impossible to imagine* the causes of the process you’re studying: in other words, to go into *temporary* and *imaginary* exile in order to represent the situation that makes your *permanent* exile impossible.

This approach is remarkably illustrated by QBism (Quantum Bayesianism) and its profound redefinition of scientific realism. QBism halts all attempts to represent a reality exterior to ourselves and proposes a bold alternative. Its aim is to provide a way of finding our way around a reality from which we cannot detach ourselves, and to hint at certain features of this all-encompassing reality, based on the constraints it exerts on the structure of our orientation. QBism was first put forward<sup>23</sup> in 2002 and has been constantly developed and overhauled<sup>24</sup> since then. It is based on a few key ideas that all tend to make quantum physics into a physics of participation, of involvement, not to say entanglement, of the researcher in the (non-)object of her research. There are three key ideas. (1) The quantum state vectors, and the probabilities they allow us to calculate, denote personal judgments on the part of the agent, or more precisely a personal tendency to *bet* on future occurrences. Quantum theory in its entirety

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<sup>23</sup> C. Caves, C. Fuchs, and R. Schack, “Quantum probabilities as Bayesian probabilities”, *Physical Review A*, 65, 022305, 2002

<sup>24</sup> B. Stacey, “Ideas abandoned enroute to QBism”, [arXiv:1911.07386v2](https://arxiv.org/abs/1911.07386v2) [quant-ph], 2019

must thus be seen as a “user’s manual” for organised betting, to be used by everyone; and not as the description of a world entirely exterior to us. (2) The bets in question bear on events emerging from an experimental intervention by the agent in the world in which he is immersed, and not on events imagined to occur spontaneously by themselves. What’s more, these events can only be considered to have occurred when they manifest themselves as experiences of the agent. (3) The status of quantum theory is normative, not descriptive. It imposes norms in order to structure our bets on events that give rise to our interventions *in* the world. It describes nothing *about* this world, even if we suspect that the norms that make it possible to find our way *in* the world carry indirect clues to what it is.

The new concept of realism that QBism promotes is then called “participatory realism”<sup>25</sup>. It’s a realism for people who takes part in the world, rather than for people who prefer to look at it as if they were standing in some ectopic place. This transition from contemplation to participation is effectively expressed by a correction to the very vocabulary of experimental intervention. The latter is no longer called an *interaction* between apparatus and object, but an *intra-action* at the heart of a block-universe that will only allow itself to be divided into two entities (apparatus and object) at the end of a process that leads to the emergence of the event. As Christopher Fuchs writes, quoting Karen Barad<sup>26</sup>: “I use the term intra-action to emphasize the lack of a natural object-instrument distinction, in contrast to interaction, which implies that there are two separate entities; that is, the latter reinscribes the contested dichotomy... That is, the ambiguity between object and instrument is only temporarily contextually decided; therefore, our characterizations do not signify properties of objects but rather describe the intra-action as it is marked by a particular constructed cut chosen by the experimenter”<sup>27</sup>. Associated with this “intra-active” concept of experimentation is an ontology that I have associated with Merleau-Ponty’s intra-ontology (or endo-ontology)<sup>28</sup>. It is an ontology for one who participates in Being, as opposed to an ontology of the observer of beings. But it is also a *phenomenological* ontology that unifies the pragmatic, realist and experiential components of QBism under the aegis of the latter<sup>29</sup> and which ultimately dissolves the residues of “external” realism irresistibly

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<sup>25</sup> C. Fuchs, “Participatory realism”, [arXiv:1601.04360v3](https://arxiv.org/abs/1601.04360v3) [quant-ph], 2016

<sup>26</sup> K. Barad, *Meeting the Universe Half-Way*, Duke University Press, 2007

<sup>27</sup> C. Fuchs, *My Struggles with the Block-Universe*, arXiv:1405.2390v2 [quant-ph], 2015, p. 26

<sup>28</sup> M. Bitbol, “A phenomenological ontology for physics: Merleau-Ponty and QBism”, in: H. Wiltsche & P. Berghofer, (eds.), *Phenomenological approaches to physics*, Springer, 2020. See R. Barbaras, *De l’être du phénomène*, Jérôme Millon, 1993

<sup>29</sup> Pienaar J., “Extending the agent in QBism”, *Foundations of Physics*, 50, 1894-1920, 2020; L. de la Tremblaye and M. Bitbol, “Towards a phenomenological constitution of Quantum Mechanics: a QBist approach”, *Mind and Matter*, 20, 35-62, 2022

evoked by the process that involves representing, as if from outside, an inseparable reality in which the experimenting agent takes part.

## 2.9 Quantum indeterminacy in the framework of an ontology of the interface

The idea of quantum indeterminacy that QBism supports flows naturally from its “participatory realism” and the way it substitutes intra-action for interaction. Understanding what it all means is quite hard work, however, as QBist statements can sometimes be misleading. Perhaps one of the most confusing is: “All that matters for a personalist Bayesian is that there is uncertainty for whatever reason. There might be uncertainty because there is ignorance of a true state of affairs, but there might be uncertainty because the world itself does not yet know what it will give—i.e., there is an objective indeterminism. [...] QBism finds its happiest spot in an unflinching combination of “subjective probability” with “objective indeterminism.”<sup>30</sup>. Reading this, it seems that the old dualism of the epistemic and the ontic, the subjective and the objective, has been embraced without discussion. It seems we have no alternative to pitting the ignorance of the subject against the intrinsic indeterminacy of the object; and QBism bizarrely combines these two options by attributing a subjective status to quantum probabilities and an objective status to the randomness for which these probabilities provide a quantitative estimation. In an article summing up the positions of QBism, Blake Stacey confirms the above combination: “According to QBism, the value of each probability is a personal property of the agent who assigns it. However, the QBist world has an objective and irreducible indeterminacy”<sup>31</sup>.

If we dig deeper, however, we see that the dualistic dichotomy becomes a little less clear-cut. The world to which the QBists attribute objective indeterminacy is not an external world that exists independently from the agent exploring it. It’s an entirely correlational world, a world that is inseparable from the experimenting agent, a world that only presents itself in the lived experience of the agent as an intra-active event. This corrective, which is almost a U-turn, can be found at least as often in the writings of QBist authors as the preceding pseudo-objectivist idea of quantum randomness. “The quantum mechanical indeterminism doesn’t come about from an indiscriminate swerve in the path of an atom; it comes from the point of contact between the theory and the world—the measurement”<sup>32</sup>. Here, the most archetypal idea of randomness-

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<sup>30</sup> C. Fuchs, *My Struggles with the Block Universe*, arXiv:1405.2390v2 [quant-ph] 2015, p. 2108. See also: C. Fuchs, “QBism, the Perimeter of Quantum Bayesianism”, arXiv:1003.5209v1 [quant-ph], 2010

<sup>31</sup> B. Stacey, “QBism and the Ithaca desiderata”, arXiv:1812.05549v1 [quant-ph], 2018

<sup>32</sup> C. Fuchs, *My Struggles with the Block Universe*, op. cit. p. 1249

in-itself, Lucretius' *clinamen*, is explicitly discarded and replaced by a correlational interpretation of quantum randomness. This correlational concept is pushed as far as its ultimate consequence: that of the autonomy of correlation, of its absolute newness with respect to the terms it connects. "In the case of quantum measurement, the uncertainty is there because the outcomes do not pre-exist the measurement. Measurement is an act of creation, bringing something new into the world: That is the ultimate reason for the uncertainty. And what more can a poor quantum gambler do but express his beliefs about what will come into existence?"<sup>33</sup>. In response to the newness of the correlational event, all the agent/researcher involved in the correlation can do is formulate his own predictive beliefs about what is poised to emerge in the wake of her own interventions. But however personal those beliefs may be, they are not at all arbitrary. So as not to be inevitably contradicted, they have to be organised into a system subject to norms of internal and praxical<sup>34</sup> coherence whose motivation can be shared intersubjectively. These composite norms are precisely those of quantum theory.

An essential aspect of the QBist research programme then entails sorting the norms that govern quantum probability into (a) simple constraints applying to internal coherence and (b) constraints on praxical coherence which, being exerted on the interface between the agent and the world, can provide information about the latter via the correlational totality we form along with it<sup>35</sup>.

It bears repeating, however, that the indirect information we can glean about the world by examining the norms that constrain the acts of experimentation and anticipation of outcomes that we carry out within it are in no way equivalent to acquiring an external view of a world seen as just a big object. The impossibility of stepping outside the world in order to look at it is actually the very root of quantum indeterminacy. Seeking to overcome or circumvent this impossibility by using rules that allow us to predict something about it would be tantamount to denying indeterminacy at its source. What the analysis of probabilistic quantum norms teaches us thus has nothing to do with any representation of the world. They are simply a codification of what the way the world works owes to the fact of being in it. This is how we must interpret

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<sup>33</sup> C. Fuchs, *My Struggles with the Block Universe*, op. cit. p. 1403

<sup>34</sup> Praxical coherence can be defined, in the manner of Ian Hacking, as: "(...) the coherence of thought, action, material, and [graphical or digital output from measuring devices]". I. Hacking, « The self-vindication of the laboratory science », A. Pickering (ed.), *Science as practice and culture*, Chicago : The University of Chicago Press, 1992. Also : M. Bitbol, « Néo-pragmatisme et incommensurabilité en physique », *Philosophia Scientiae*, 8 (1), 203-234, 2004

<sup>35</sup> J. DeBroda, C. Fuchs, J. Pienaar, and B. Stacey, "The Born rule as Dutch-Book coherence (and only a little more)", arXiv:2012.14397v1 [quant-ph], 2020

Christopher Fuchs' alternative description of quantum indeterminacy: "Anyway, remember the notion of indeterminism I am aiming for [...] is only that each piece of the world truly has the power to make a contribution to the whole, a contribution that can't be seen from the outside . . . but may well be surmised from the inside. And it is from the inside that the agent draws his probability assignments."<sup>36</sup>

This form of indeterminacy is clearly not made necessary because of the intrinsic indeterminacy and absolute "hyperchaos" of some hypothetical "thing-in-itself", but because of the very impossibility of detaching the "in-itself" from the "for-us". This is why the only invariants accessible to quantum physics are the tools of an original kind of probabilistic calculus that assumes the consequences of the entanglement and unanalyzability of the phenomena it is applied to. Such are the state vectors in a Hilbert space, or the complex amplitudes of probability derived from it.

## Epilogue

With the above thoughts, I wanted to play a few harmonic variations on the somewhat paradoxical theme of an "ignorance-driven" randomness, for which the prospect of resolving ignorance is non-existent, or, alternatively, an indeterminacy connected to a radical boundary of knowledge for which, by definition, there is no exterior. Neither ontic nor epistemic, quantum indeterminacy can be termed *interfacial*. Regulated by the Heisenberg inequalities, quantum indeterminacy defines the scope of knowledge as we make a systematic journey along its elsewhere-less edges. And it reciprocally defines the form of the known world by identifying it with the contours of this uncrossable outer rim.

This approach to quantum indeterminacy is profoundly incompatible with the idea of "laws of nature" upheld by speculative materialism. The latter doctrine contends that we can distinguish two levels of indeterminacy: (1) the absolute contingency of "laws of nature" themselves (which could have been, and still could be, something other than what they are), and (2) randomness that characterizes certain events governed by the current laws of nature [Harman, 2011]. The possibility of change in the laws of nature cannot be quantified, whereas the possibility of the random occurrence governed by these laws can, which justifies assigning an *objective* probability to it—objective in the strict, pre-critical sense of "inherent in nature-in-itself". So, what about quantum physics?

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<sup>36</sup> C. Fuchs, *My Struggles with the Block Universe*, op. cit. p. 1809



First, the events it seeks to predict are interactive rather than spontaneous, correlational rather than absolute. There is thus no reason to consider their probabilities as “objective” in the pre-critical sense. If we can quantify the degree of possibility of events, it is not because they are framed by a pre-existing “law of nature”, but because, as they are caused and identified by finite beings in relation to their environment, predicting them is precisely conditioned by the finite capacities of these beings. As Bruno De Finetti writes [1989], justifying his idea of probability, “I do not seek to know why the fact I predict will occur, but why I predict that the fact will occur”. More broadly, we don’t have to explain why the possibility of events is quantifiable, but only to show how we quantify the possibility of the events. It is this task that De Finetti’s “subjectivist” theory of probability sets itself, and which is amplified by the QBist approach to quantum theory.

Second (this is the above-mentioned amplification), what we call “laws of nature” in quantum physics do not govern events that spontaneously occur in nature, but only the probabilities that *we* assign to events that *we* co-produce. We just have to look at two key examples of these laws of quantum physics, Schrödinger’s equation and Heisenberg’s uncertainty principle, to convince ourselves of this.

Schrödinger’s equation governs the evolution of a “state vector” whose only function is to allow us (via the “Born rule”) to calculate the probability of these events co-produced by us. As such, the Schrödinger equation has nothing contingent about it at all. Its general form is made *necessary* by the fact that other forms would result in the loss of the probabilistic status of predictions over time. Instead of the speculative contingency of *laws of nature* advocated by Quentin Meillassoux, we have an epistemological necessity inherent in the law of the *theory*: that of constantly putting forward a coherent system of probabilistic predictions; that of transforming, over time, one coherent probabilistic system into another coherent probabilistic system.

The same goes for Heisenberg’s uncertainty principle. Heisenberg’s inequalities are thought to be limiting because they assign a boundary to the accuracy of the joint measurement of two canonically conjugate variables (such as position and quantity of motion). But they also operate *as if* they were “laws of nature”, because they make it possible to predict remarkable observable effects. They allow us, for example, to predict the bandwidth of electromagnetic emission and absorption lines in the atom or the pressure exerted by vacuum fluctuations on parallel mirrors (Casimir effect). Heisenberg inequalities govern only probabilistic quantities: they govern the mean quadratic divergence of variables but not the variables themselves. On the other hand, they can be quantitatively derived from relations of commutation between

observables; in other words, they can be derived from a mathematical expression of the impossibility of detaching measured values from the context and order of the measurements. The Heisenberg inequalities are thus made *necessary* by the fact that this detachment is impossible, in other words by the essentially correlational nature of knowledge in quantum physics. Here again, instead of the speculative contingency of “laws of nature”, we have an epistemological necessity: that of a “restriction” of knowledge turned into a predictive law of phenomena co-produced by us.

Here, necessity is internal to correlation and results from correlation. It does not characterize the contingency of the laws of some allegedly autonomous nature, but the theoretical law that governs the contingency of correlational phenomena, based on which we *constitute* a domain of objectivity and what we call “nature”.