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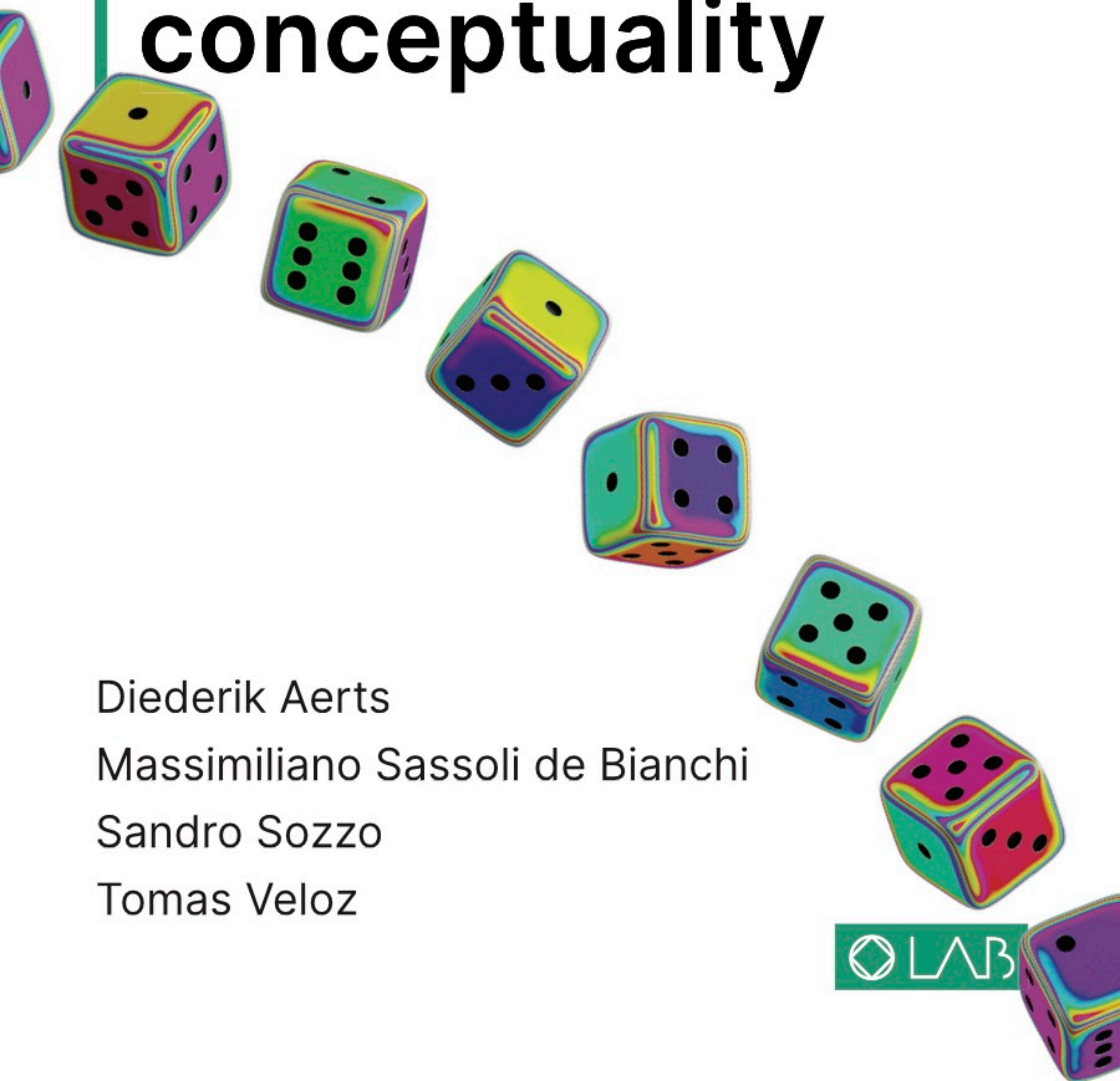
Quantum physics relativity and conceptuality



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Index

The pages of a book, whether paper or electronic, possess a peculiar property: they are able to accept whatever variety of letters, words, phrases and illustrations, without ever expressing a criticism, or disapproval. It is important to be aware of this fact when we go through a text, so that the lantern of our discernment can always accompany our reading. To explore new possibilities, we must remain open-minded, but it is equally important not to succumb to the temptation to uncritically absorb everything we read. In other words, the warning is to always subject the content of our reading to the scrutiny of our critical sense and personal experience. The editor and the authors can in no way be held responsible for the consequences of a possible paradigm shift induced by the reading of the words contained in this volume.

Editorial

This – all in English – twenty-first volume of *AutoRicerca* is dedicated to physics and contains four articles addressing foundational topics of quantum mechanics and relativity theory. All of these four articles touch, in a more or less specific way, the so-called *conceptuality interpretation* of quantum (and relativity) theory, initially proposed by *Diederik Aerts* and currently investigated within his "Brussels group," at the *Center Leo Apostel for Interdisciplinary Studies* (CLEA).[1]

In particular, the third of these four articles presents an extensive review (82 pages) of this fascinating and challenging interpretation, which I had the pleasure to write in collaboration with *Diederik Aerts*, *Sandro Sozzo* and *Tomas Veloz*. The article was first published in 2018, in Springer's journal *Foundations of Science*, and I am glad to be able propose it here again to the readership of *AutoRicerca*, together with other articles that revolve around the same theme.

This article is an extended version of a plenary talk I gave at the *Worlds of Entanglement* symposium,[2] back in September 2017, in Brussels, which included numerous sessions on varied topics: quantum foundations, non-classical probabilistic structures, frontiers of quantum physics, quantum beyond physics, entanglement in social sciences, complex systems, quantum artificial intelligence, worldview integration, decisions under uncertainty, entanglement and consciousness.

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[1] CLEA is an interfaculty center of the *Vrije Universiteit Brussel*, whose mission is bridging the different scientific, social and cultural disciplines.

[2] The symposium was the natural continuation of past events organized by the *Centre Leo Apostel for Interdisciplinary Studies* (CLEA), in particular the *"Einstein meets Magritte"* conference (1995), and the *"Times of Entanglement"* symposium (2010), which brought together some of the world's most renowned thinkers, such as Zygmunt Bauman, Brian Arthur, Ilya Prigogine, Heinz von Foerster, William Calvin, Bas van Fraassen, Bob Edwards, Adolf Grunbaum, Rom Harré, Chris Langton, Constantin Piron, Francisco Varela, Linda Schele, Robert Pirsig, Barbara Hernstein-Smith, John Ziman, among others, to develop an interdisciplinary dialogue about fundamental issues of science and society.

In my presentation,[3] I explained how one can understand the strange behavior of quantum (and relativistic) entities by adopting a bold hypothesis about their nature. Quoting the French physicist *Jean-Marc Lévy-Leblond*:[4]

> It is to be realized today […] that quantum theory does exist and that its concepts, after a century of collective practice, are deeply rooted in the present common sense of working physicists. These concepts need no longer be approached from classical ones, but may, and should, be taken at their face value. Such an intrinsically quantum understanding leads one to recognize that the objects of quantum physics are not either waves or particles, as duality would want us to believe; they are *neither waves*, *nor particles*, even though they do exhibit, under very particular circumstances, two types of limit behaviour as (classical) waves, or (classical) particles […]. It has been proposed to stress this ontological point by calling them "quantons."

The bold hypothesis at the basis of the conceptuality interpretation (as proposed by Aerts in 2009) is that "quantons," in the ultimate analysis, would be nothing but *cognitons*,[5] that is, not *objectual entities*, but *conceptual entities*. This, however, not in the sense that quantum (and relativistic) entities would be the same as human concepts, but in the sense that they would share with the latter a similar conceptual nature, in the same way, say, sea waves and sound waves, although very different entities, can share a similar undulatory nature.

All this will be clearly explained and motivated in the mentioned review article, which was written having in mind an interdisciplinary audience, hence readers that are not necessarily specialists in physics. However, it was certainly written for a scientifically literate

[3] You can find a video with the content of my talk on my YouTube channel: *https://youtu.be/-SteQN1A33M*.

[4] Lévy-Leblond, J.-M. (2018). On the Conceptual Nature of the Physical Constants. In: *The Reform of the International System of Units (SI). Philosophical, Historical and Sociological Issues*. Edited by: Nadine de Courtenay, Olivier Darrigol, and Oliver Schlaudt, Routledge, pp. 125-149.

[5] The specific term "cogniton" was introduced by *Diederik Aerts* and *Lester Bertrand*, in a recent article entitled *Quantum Structure in Cognition: Human Language as a Boson Gas of Entangled Words*; see: arXiv:1909.06845 [q-bio.NC].

readership, having a sufficient general understanding of modern physics and truly motivated in accessing explanations at the forefront of scientific research, including the very important debate about the interpretations and foundations of physical theories.

Regarding the importance of providing an interpretation to the quantum formalism, let me quote here the philosopher *Tim Maudlin*:[6]

> There is no doubt that […] there is a mathematical formalism that we know how to derive predictions from, and those predictions can be accurate to fourteen decimal places, but what a […] physical theory is, is more than just a mathematical formalism with rules, it should specify a physical ontology, which means: tell me what exists in the physical world; are there particles? Are there fields? Is there spacetime? And tell me about these things […] and the problem is that […] quantum theory isn't a theory in that sense, it is just a formalism, and then what people call "interpreting quantum theory" – which sounds like a funny thing to do cause you'd say, well, I have a theory, what is an interpretation? – what's called "interpreting quantum theory" is really the development of precise physical theories that make the same predictions or nearly the same predictions that you get out of this standard mathematical recipe […].

Countless interpretations of the quantum formalism have been proposed during the years, each one with its advantages and disadvantages. The conceptuality interpretation, however, stands out for the fact that it emerged from the recent success in using the quantum mathematical formalism in the modeling of different aspects of human cognition, like the dynamics of human concepts in human thought and decision making. This success led Diederik Aerts to cultivate the idea that it was no coincidence that the mathematical formalism of quantum mechanics was so well equipped to describe so many aspects of the human cognitive domain, that is to say, that this could be due to a deeper correspondence about the actual nature of the microphysical entities.

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[6] See his interview "The Problem With Quantum Theory," at *The Institute of Art and Ideas*: https://youtu.be/hC3ckLqsL5M.

Aerts worked on the conceptuality interpretation ideas initially in silence, but as soon as the explanatory power of the interpretation became more evident, in addressing all the difficult to understand aspects of quantum mechanics, like Heisenberg's uncertainty principle, identical particles and entanglement, he started from 2009 to publish the foundational ideas and first results of this explanatory framework, consisting in describing quantum entities as meaning (conceptual) entities.

Now, *AutoRicerca* is a journal aimed at a large audience of readers, many of whom might not easily digest the above-mentioned review article, even though it only contains very few mathematical notions. This is the reason why it is not proposed as the first essay in this volume, but is preceded by two more didactically oriented texts, so as to offer a more gradual approach to the topic.

The first article has also been recently published this year in *Foundations of Science*, in a special issue dedicated to an event which was the continuation of the previously mentioned symposium, held at the *Institute of Philosophy and Complexity Sciences* (IFICC), in Santiago de Chile, on 7-8 March 2019. It was written having in mind one of the objectives of CLEA: that of a broad dissemination of scientific knowledge. Hence, it addresses a transversal audience of readers, both academic and nonacademic.

The content of the article was also presented in a talk that I had the pleasure to give, on May 16, 2019, in Paris, at the "Bertrand" headquarters of the *European Space Agency* (ESA), in the ambit of their "Beyond Space" lunchtime series, whose scope is to present to their staff ideas going beyond space as such.[7]

The title of the article is "A non-spatial reality" and its goal is to highlight that, based on what we have learned so far about the behavior of the entities of the micro-world, we are forced to admit that they cannot be fully represented as entities belonging to our spatial (and more generally, spatiotemporal) theater. In other words, we are forced to admit that the building blocks of our physical reality are *non-spatial* in nature.

This is a crucial observation for the conceptuality interpretation, as is clear that once we observe that the quantum phenomena (like

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[7] A video presentation based on the PowerPoint of the talk can be found on my YouTube channel: *https://youtu.be/omvHPruoDMQ*.

entanglement, interference effects and indistinguishability), when attentively scrutinized, tell us that there is more in our physical reality than what can be represented in spatiotemporal terms, one is left with the pressing question of knowing what the nature of a non-spatial entity would be. And, to my knowledge, no interpretation of quantum physics has ever brought a satisfactory answer to this question, the conceptuality interpretation being really the first approach to offer a possible and credible perspective.

Coming to the second article, which I wrote with *Diederik Aerts*, it will be published in a special issue of the *Journal of Consciousness* and is based on a talk I gave at the *2nd International Congress of Consciousness*, which was held in Miami (USA), on May 19-21, 2017. This was an "unlikely event" with a surprising mixture of topics, styles and approaches, all revolving around the notion of consciousness and its numerous manifestations. My presentation was, again, about emphasizing the breakdown of our parochial spatiotemporal representation of the physical reality and the fact that the latter is so complex, and contextual, that a single viewpoint might appear to be insufficient to stage it in an all-inclusive way, as we emphasize by introducing the notion of *multiplex realism*, which we try to motivate in the article.

Among the conclusions that were reached, there is that the quantum and relativistic revolutions have not yet been fully integrated in our modern worldview, still predominantly based on purely spatial and mechanistic models, inadequate to account for all the known (inner and outer) phenomena. An extended worldview is however gradually gaining ground, although it is still perceived to be highly non-intuitive by the majority of scientists, physicists included. It is however this extended worldview that we most probably need to adopt, if we want to have a chance at understanding the complexity and richness of our world, inner and outer, spatiotemporal and non-spatiotemporal.

The above article about "Multiplex realism," and the corresponding presentation, was a sort of continuation of a talk I gave two years earlier at the *1st International Congress of Consciousness*, held at the IAC Campus, in Evoramonte, Portugal, on May 22-24, 2015. The text that I wrote at the time for the first edition of the congress was published in the *Journal of Consciousness*[8] (volume 18, year pp. 203-268), and is also proposed in this volume, to emphasize that the conceptuality interpretation might also be of interest in shedding some light on the nature of those non-ordinary phenomena that we humans are able to experience, when in more expanded states of consciousness.

I hope that the four articles presented in this volume will provide the reader with a fascinating leading-edge perspective. When reading them, there will be some inevitable repetitions, but as the Latin saying goes, *repetita iuvant*, i.e., in a learning context, repeating certain notions and reasonings several times can facilitate their understanding. Each article, however, is self-contained, hence the reader can also let herself/himself be guided by intuition and only decide to read one of them.

Whatever the reading path chosen, as always, I wish you a good reading and meditation!

Massimiliano Sassoli de Bianchi
Editor

[8] The article was also translated into Italian and published in *AutoRicerca*, Issue 10, 2015.

About the authors

Diederik Aerts, received his MSc in Mathematical Physics in 1975, from Brussels Free University (VUB). For his doctorate he worked at the University of Geneva with Constantin Piron on the Foundations of Quantum Theory, obtaining his PhD in Theoretical Physics in 1981 from VUB, with Jean Reignier. In 1976 he started working as a researcher for the Belgian National Fund for Scientific Research (NFWO), where in 1985 he became a tenured researcher. Since 1995, he has been director of the VUB's Center Leo Apostel for Interdisciplinary Studies (CLEA) and in 2000 he was appointed professor at the VUB. From 1990, he has been a board member of the 'Worldviews group', founded by the late philosopher Leo Apostel. In 1997, he became Editor-in-Chief of the international ISI and Springer journal 'Foundations of Science (FOS)'. He was the scientific and artistic coordinator of the 'Einstein meets Magritte' conference, where some of the world's leading scientists and artists gathered to reflect about science, nature, human action and society. For more information, refer to the author's personal website: *www.vub.ac.be/CLEA/aerts*.

Massimiliano Sassoli de Bianchi received the Ph.D. degree in physics from the Federal Institute of Technology in Lausanne (EPFL) in 1995, with a study on temporal processes in quantum mechanics. His current research activities are focused on the foundations of physical theories, quantum mechanics, quantum cognition, and consciousness studies (self-research). He is currently a research fellow at the Center Leo Apostel for Interdisciplinary Studies (CLEA), situated at the Vrije Universiteit Brussel in Belgium (VUB), director of the Laboratorio di Autoricerca di Base (LAB), in Switzerland, editor of its journal AutoRicerca, and president of the company Area 302 SA.

Sandro Sozzo is associate professor at the School of Business of the University of Leicester. His research interests are highly interdisciplinary and mainly concern the development of novel mathematical models of cognition and decision-making under uncertainty, with relevant applications in computer science, economics and finance. He is author of more than 80 publications, organized conferences, managed special issues as guest editor, and was invited to give lectures in UK (Oxford), US, Canada, Europe and China. He is the director of the "Research Centre for Quantum Social and Cognitive Science" (IQSCS), the secretary of the International Quantum Structures Association (IQSA) and the managing editor of the Springer Nature journal Foundations of Science.

Tomas Veloz graduated in physics (B.Sc.), mathematics (B.Sc.), and computer science (M.Sc.) from the University of Chile, in 2005, 2007 and 2010, respectively. He received the Ph.D. degree in interdisciplinary studies from the University of British Columbia in 2015. During his PhD, in 2013, he joined the Leo Apostel Centre for Interdisciplinary Studies (CLEA), at the Brussels Free University (Vrije Universiteit Brussel— VUB), as a research fellow, and since 2014 he has been the director of the Systemics department of the Institute of Philosophy and Complexity Sciences (IFICC) in Santiago, Chile. In 2016–2017 he worked as a postdoctoral researcher at CLEA. He is currently a postdoctoral researcher at IFICC.

AutoRicerca

A non-spatial reality

Massimiliano Sassoli de Bianchi

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Abstract

It is generally assumed, and usually taken for granted, that reality is fully contained in space. However, when taking a closer look at the strange behavior of the entities of the micro-world, we are forced to abandon such a prejudice and recognize that space is just a temporary crystallization of a small theatre for reality, where the material entities can take a place and meet with each other. More precisely, phenomena like quantum entanglement, quantum interference effects and quantum indistinguishability, when analyzed attentively, tell us that there is much more in our physical reality than what meets our three-dimensional human eyes. But if the building blocks of our physical reality are non-spatial, what does it mean? Can we understand what the nature of a non-spatial entity is? And if so, what are the consequences for our view of the world in which we live and evolve as a species? This article was written having in mind one of the objectives of the Center Leo Apostel for Interdisciplinary Studies, that of a broad dissemination of scientific knowledge. Hence, it addresses a transversal audience of readers, both academic and nonacademic, hoping to stimulate in this way the interdisciplinary dialogue about foundational issues in science.

1 Introduction

According to *Plato*'s famous *allegory of the cave*, we are like prisoners chained from time immemorial in a dark cave, only watching and studying flickering shadows on a *wall*, believing that those *shadows*, and the surface of the wall, are all that exists in our reality. In Plato's allegory, one distinguishes two levels: the *empirical* or *spatiotemporal* level, which is that of the *appearances*, and the *ontological level*, considered to be that part of the world that remains unperceived by our ordinary senses but somehow could be understood by our intellect. In other words, the ontological level is that of the "real entities," whereas the empirical level is that of the "appearances of these same real entities." To put it differently, following Plato's allegory, higher-dimensional entities, having a "deeper" reality, would exist, casting all sorts of shadows onto the lower-dimensional "wall" of our humanly constructed spatial (or spatiotemporal) representation.

A similar allegory was conveyed by the English schoolmaster *Edwin A. Abbott*, in his "Romance in Many Dimensions" (Abbott, 1884), written to criticize the Victorian culture. According Abbott's allegory (which was famously used by *Carl Sagan* in his 1980s "Cosmos" TV series, to explain the difficulties we have in visualizing a world of four dimensions), we are pretty much like the residents of a *Flatland*, i.e., low-dimensional beings living in a "thin layer" of a much vaster reality; a layer that is constantly traversed by entities of higher dimensionality that we cannot perceive in their fullness.

As an example, imagine a lake in a beautiful spring day. Its surface defines three distinct worlds. There is the down-world, rather thick, populated by three-dimensional aquatic creatures such as fish; there is the up-world, more rarefied, also populated by three-dimensional creatures, like birds; and there is the "flatland middle-world," as defined by the very surface of the lake, a reality of an intermediate density populated by essentially two-dimensional creatures, like small wingless insects that never leave the thin film of water.[1]

According to Abbott, we humans are somehow like the flat creatures of this middle-world, with all the perceptual (and cognitive) disadvantages it entails. Imagine being one of the insects that live at the boundary between the up-world and the down-world, not knowing being at the frontier of realities of higher dimensionality, as you always lived in a two-dimensional environment, with a two-dimensional body, and you cannot directly experience a third dimension, or a fourth, a fifth, etc. (see Figure 1).

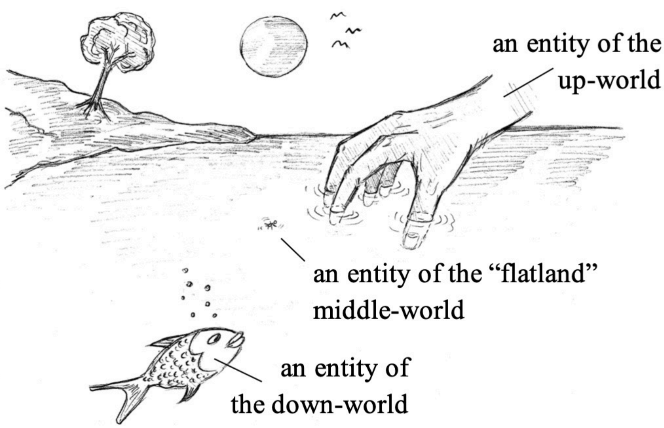

Figure 1 Abbott's allegory of Flatland here exemplified as the middle-world defined by the two-dimensional surface of a lake.

Then, suppose that a three-dimensional entity of the up-world, say a human hand, dips its five fingers into the water. From the limited perspective of a middle-world creature, you will see appearing out of nowhere five strange entities, more or less spherical, that for just a moment will manifest in your space (see Figure 2). Surely, you will mistake those ephemeral traces for genuinely two-dimensional individual entities, completely separated and independent from one

[1] Of course, strictly speaking, the small wingless insects living on the surface of the lake are still three-dimensional entities, so our example must be understood in an ideal sense, thinking of the insects on the surface as genuine two-dimensional beings, likewise the inhabitants of Flatland, in Abbott's novella.

another. Nonetheless, from the perspective of a three-dimensional hyper-entity of the up-world, it is clear that those five spherical-entities are not separate, but interconnected: they are part of a unitary three-dimensional entity and they only appear separate when their higher dimensional structure is viewed from the limited perspective of a two-dimensional representation.

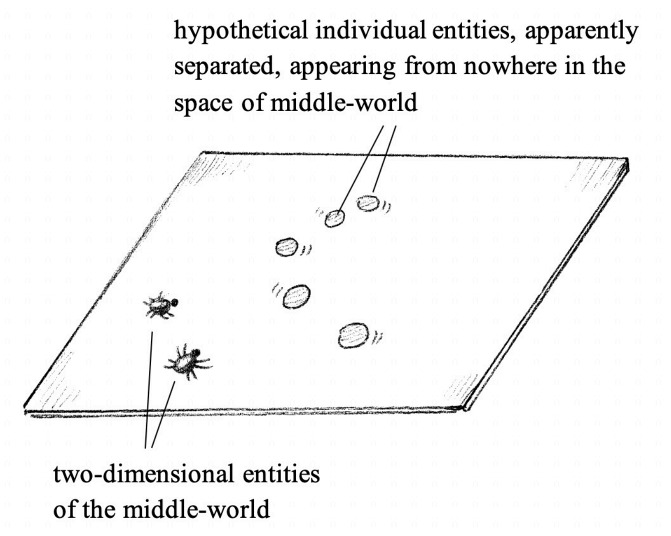

Figure 2 The inhabitants of a two-dimensional world might mistake a single whole three-dimensional entity, like a hand, as five separated entities, moving one independently of the others.

What we will try to do in this article, is to explain why Plato and Abbott, in their bewildering allegories, had a correct perception about our reality, when sensing that a lot was indeed happening "behind the scenes" of our spatial representation, without our knowledge. But we will also try to indicate what Plato and Abbott were not able to guess: the nature of the entities populating these "behind the scenes" of our spatial representation, and how they can relate with the latter.

Now, if it is true that space (and more generally spacetime) is not the container of our physical reality, but only a specific theater in which a very parochial representation is taking place, the first thing we must address is how we came to consider such representation in the first place, then mistaking it for everything that exists. In other words: *How did we construct our spatial theater*?

This has to do with the fact that, as a species, we have evolved since hundreds of thousands of years in a very particular niche of our reality: that of the surface of our beautiful planet Earth. As Sagan used to say, contemplating the picture of our planet taken in 1990 by the *Voyager 1* space probe, from a distance of about 6 billion kilometers, "Earth is a very small stage in a vast cosmic arena." This is certainly true when we compare our planet with the immense spatial "cosmic dark" in which it is immersed. But our planet, and the entities with which we have interacted at its surface by means of our dense bodies, are also in turn "vast cosmic arenas," if we compare them with the so-called microscopic "particles" forming them. By this we mean that we have been surrounded by quite some particular physical entities, of a macroscopic size, and from our multiple interactions with these entities, which we experienced by means of our dense human bodies in a rather hot environment, we started a long time ago the construction of a prototypical *worldview*, in the attempt to order our experiences into a consistent *map of relations*.

From this pre-cultural and pre-scientific construction, a first *clothing and decoration* of reality resulted, allowing us to identify those portions of it that were recognizable as *aggregates of sufficiently stable properties*, where by 'stable' we mean that the properties characterizing these aggregates could remain *actual* for long enough to become easy to observe. These aggregates of relatively permanent properties (think of a piece of matter having a given size, weight, temperature, etc.) were what we today call, in physics, *classical entities*, or *macroscopic objects*, or simply *objects*, *bodies*, etc., which also include the astronomical bodies we can see moving in the sky, like the Moon and the Sun, obeying with good approximation the laws of non-relativistic classical mechanics.

One can distinguish two different fundamental *directions of penetration* in our pre-cultural process of clothing and decoration of reality (Aerts & Aerts, 2004). One direction, which we have just mentioned, is a *penetration in depth*, through which we have initially identified those phenomena that, according to our senses, particularly those of sight and touch (Aerts, 2014), stood out compared to others, because of their *availability* in interacting with our bodies and becoming part of our experiences, and also because such availability persisted long enough, so allowing us to have multiple experiences with them. In other terms, by means of our penetration in depth of reality, we have recognized the existence of *experientially separated and stable* portions of it.

The second, in a sense complementary direction of penetration, can be called *penetration in width*. It corresponds to our effort to organize and order the content of our experiences with all these different *aggregates of stable properties*, i.e., with the different physical objects that appeared to us to be separated, in the sense of not being part of a same aggregate and not influencing each other in a significant way. This process of penetration in width, through which we have identified the more important and evident relations among these entities of our ordinary experiences, can be understood as an *ordering process giving rise to a space*. And since our practical experiences were essentially with classical entities, the *space of relations* that emerged is what we call today the *three-dimensional Euclidean space*.

In other terms, *space* can be essentially considered as *a specific theater of reality that emerged when a given set of experiences was properly ordered and organized*, i.e., put in relation to each other (Aerts & Aerts, 2004). The reason why such a specific *theater of reality* has been mistaken over time for a fundamental substantive container for the latter (a position still maintained today by many if not the majority of scientists) is easy to understand: as time went by, we have simply forgot about our construction, and since the typology of our experiences remained basically the same, it was easy and natural to start believing that all of our reality would necessarily fit into such theater, so that the theater and its content, and reality, would just be one and the same thing. This belief, however, becomes difficult (if not impossible) to maintain in our days as following the discoveries of modern physics genuinely new experiences were accessed, in controlled experimental contexts, with entities behaving very differently from those discovered in our initial process of 'penetration in depth', and which rather stubbornly did not lend themselves to be included, or fully included, in the relational space that was built thus far.

2 Entanglement and non-spatiality

A paradigmatic example of the breakdown of our Euclidean spatial theater construction is the discovery of *quantum entanglement*. At the theoretical level, it was initially discussed by *Einstein*, *Podolsky* and *Rosen* (1935) and by *Schrödinger* (1935), and its existence has now been firmly established in numerous experiments, starting from the historical ones performed with photons, in 1982, by the French group of *Alain Aspect* (Aspect et al, 1982; Aspect, 1999).

In a nutshell, two entities are in an *entangled state* if they can be spatially separated by arbitrary distances and yet remain invisibly interconnected, so that they are able to influence each other or behave as if they were a single entity. Well, to say it all, the notion of entanglement in quantum theory does not depend in any way on whether the two entities are spatially separated or not, but it is certainly when this is the case that the truly non-ordinary aspect of the "entanglement relationship" becomes evident.

The reason why entanglement is incompatible with our Euclidean construction is very simple to understand. As we said, during our penetration in width of reality we have constructed a spatial representation of the different possible relations between the entities that we could identify. In this representation, the notion of *spatial distance* was also used to describe the *degree of experimental separation* between entities, in the sense that the greater their spatial separation the lesser their possible mutual influences (*principle of locality*). Now, for two entities to be *experimentally separated*, let us call them entity A and entity B, it means that when we test a property on entity A the outcome of the test will not depend (in an ontological sense) on other tests we may perform (simultaneously or in a sequential way) on entity B, and vice versa (Aerts, 1984). For ordinary classical/spatial entities this is guaranteed whenever the distance separating them is sufficient to guarantee that no signal can have the time to propagate between them to possibly influence the outcomes of their respective tests, before their execution. And more generally, this is guaranteed whenever there is no 'third element of reality' that would connect the two entities in some way. And of course, if such connecting element would be present and detectable, we would not say anymore that the two entities are spatially separated, but that they form a single interconnected whole.

So, *spatial separation* and *experimental separation* were in a sense considered to be synonyms, as the former was precisely used to characterize the latter, during the construction of our Euclidean theater. But let us now explain how entanglement is revealed in experiments conducted in the physics' laboratories. This is done by analyzing possible *correlations* resulting from the execution of *joint measurements* (i.e., joint observations) on composite systems. This is however a subtle issue as also entities that are experimentally separated can have some of their properties strongly correlated. For this, it is sufficient that they were once connected in their past and were subsequently disconnected by some physical process, in such a way that the process of disconnection *created correlations*.

It was the great merit of the Northern Irish physicist *John Bell* to have proposed specific inequalities, nowadays called *Bell inequalities* (Bell, 1964, 1971), only involving quantities that are experimentally accessible, able to test if the observed correlations were already existing prior to the joint measurements, hence were only *discovered* by the latter, or if the correlations were only *potential* prior to the measurement, hence were literally *created* by the latter.

The Belgian physicist *Diederik Aerts* proposed to call the former *correlations of the first kind* and the latter *correlations of the second kind*, being those of the second kind which are typical of quantum entanglement (Aerts, 1990). More precisely, and roughly speaking, correlations of the second kind can violate Bell's inequalities, and therefore reveal the presence of entanglement, whereas correlations of the first kind cannot violate Bell's inequalities, and therefore describe a situation of experimental separation.

Let us provide a famous example of correlations of the first kind, i.e., of correlations that are not considered to be the signature of quantum entanglement: Bertlmann's socks (Bell, 1981). Dr. Bertlmann was a colleague of Bell, who liked to always wear socks of different colors. Of course, it was quite unpredictable which color he would have on a given foot on a given day, but if one was able to see that the first sock was, say, pink, one could obtain immediate information about the fact that the other sock would be non-pink (see Figure 3). Of course, no mystery here: the color of the two socks pre-existed their observation; it is not something that was created by the latter, but just discovered during it.

Is it also possible to provide a simple example of a system exhibiting correlations of the second kind, which are typical of quantum entanglement? The answer is affirmative. Consider an experiment where two persons (let us call them Alice and Bob, as is traditional in physics), simply hold the two ends of an unbroken elastic band of length L, and by pulling them they break it in two parts (Aerts, 2005; Sassoli de Bianchi, 2013a). This is clearly a situation where correlations are of the second kind, as the respective lengths of the two fragments are created in a genuinely unpredictable way by the joint action of Alice and Bob (see Figure 4). However, they are always perfectly correlated, as their sum must always be equal to the length L of the unbroken elastic band.

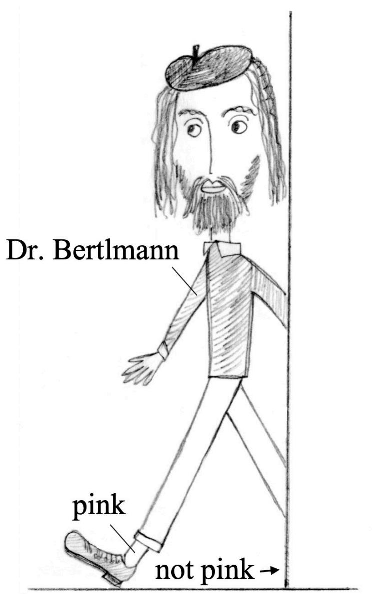

Figure 3 A depiction of Bertlmann's socks situation, as described in Bell's 1981 paper entitled "Bertlmann's socks and the nature of reality" (Bell, 1981).

It is important to remind that *quantum measurements*, i.e., *quantum observations*, are processes that can create the very properties that are meant to be tested, i.e., observed, as in general they are only potential prior to their observation. As a consequence, when observations are performed in a joint way on a given system, they can create (actualize) correlations that were only potential prior to the join observation. Alice and Bob breaking an elastic band by their joint actions, creating in this way different possible correlated couples of outcomes, like $(d_1, L - d_1)$, $(d_2, L - d_2)$, $(d_3, L - d_3)$,…, is a perfect exemplification of this situation, and in fact it can be proven that the process of breaking elastic bands is able to violate Bell's inequalities (Aerts, 2005; Sassoli de Bianchi, 2013a, Aerts et al, 2019).

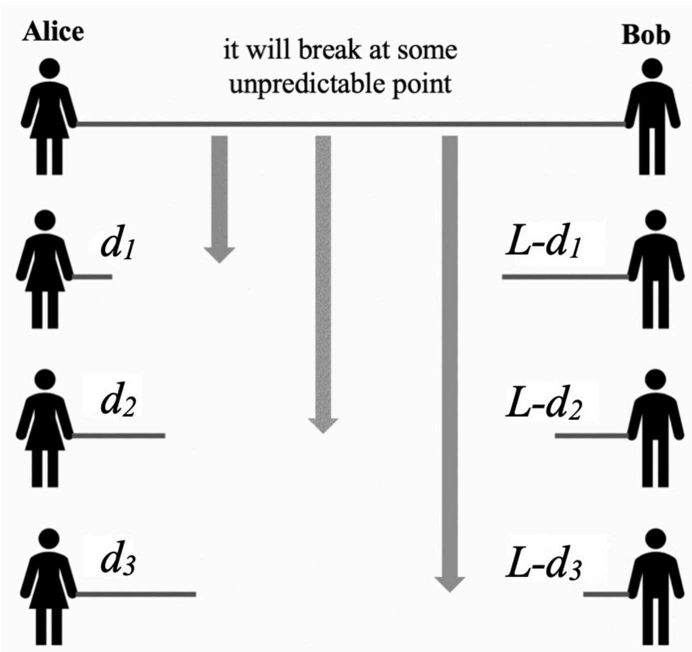

Figure 4 Three possible outcomes of a process of breaking an elastic band. Although the obtained lengths of the two fragments can be different at each 'breaking experiment', they are also perfectly correlated, as their sum is always equal to the total length L of the unbroken elastic.

To make perfectly clear the difference between a situation capable of creating significant correlations, compared to a situation where this is not the case, let us consider another simple example. Imagine that Alice and Bob hold each of them a die in their hands. If they jointly roll their die, say on a table, they will obtain a couple of upper faces, which correspond to the outcome of their joint "rolling experiment." Assuming that the two dice are not rigged, and considering that they are experimentally separated entities, not influencing each other in whatsoever way, 36 different couples of outcomes will be obtained with equal probability (see Figure 5). This is clearly a situation where there are no correlations.

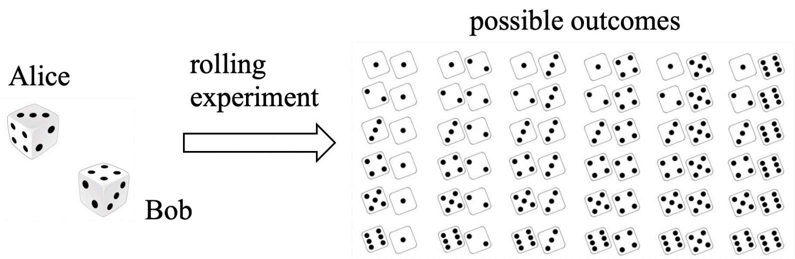

Figure 5 By rolling two unconnected dice, 36 equiprobable pairs of different upper face outcomes can be obtained. Even though for each dice an upper face is created in an unpredictable way, the outcomes obtained for each die are completely independent of one another, hence no correlations are created by the joint rolling experiment and Bell's inequalities cannot be violated.

Imagine now that the two dice are connected in some way, so as to form an "entangled double-die system." This can be done by linking them *through space* by means of a rigid rod, whose two ends are attached at the center of two of their opposed faces, as indicated in Figure 6. Then, the presence of the rod only allows Alice and Bob to roll their die along a same direction, perpendicular to the rod, so that this time only 4 pairs of upper face outcomes can be obtained (see Figure 6). So, we now have a process where correlations are created in an unpredictable way, and this is again a situation where Bell's inequalities will be violated (Sassoli de Bianchi, 2013b, 2014).

The above examples should not be considered just as useful didactical tools: they also allow to get rid of the misconception that a violation of Bell's inequalities would only be specific to the micro-world (Aerts et al, 2000, Aerts & Sassoli de Bianchi, 2018). Classical macroscopic entities can also violate them, if the joint experiments performed by Alice and Bob are able to *actualize potential correlations*, which will generally be the case if the composite entity on which they act forms a whole, because its component parts are *connected* in some way. In the case of the unbroken elastic band, the connection is provided by the very substance of the elastic, and in the case of the two dice by the rigid rod. These connections are elements of reality that we can represent and detect within our three-dimensional Euclidean space. In other words, they are *spatial connections*.

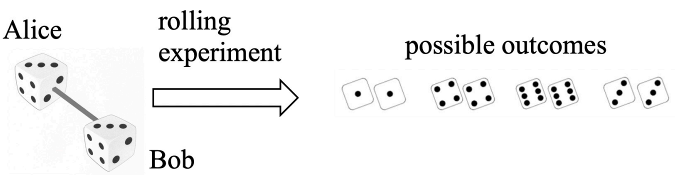

Figure 6 By connecting the two dice, only 4 equiprobable pairs of upper face outcomes can be actualized. Hence, correlations are created by the joint rolling experiments and Bell's inequalities will be violated.

Here comes the fundamental difference between two dice entangled by means of a rigid rod, or two elastic fragments entangled within an unbroken elastic band, and the situation of two entangled micro-entities, like say two entangled electrons, or two entangled photons. Indeed, in the latter cases the connections that create the correlations remain hidden, not only because mathematically speaking they cannot be represented in a 3-dimensional space, but also because, experimentally speaking, there is nothing detectable in the space between two spatially separated entangled micro-entities. Despite of that, the two entities can still give rise to correlations of the second kind or behave as if they would form a single whole entity and, in this way, give the impression that they can influence each other at a distance.

Einstein famously described this puzzling situation as a "spooky action at a distance" and physicists nowadays use for it the term of *non-locality*. However, if quantum entanglement expresses a form of connectivity that does not happen in space, i.e., that is the consequence of the presence of *non-spatial connections*, the correct term to be used is not *non-locality*, but *non-spatiality*. And this means that microscopic entities would generally not be in space but be brought in space only when interacting with macroscopic entities like the measuring apparatuses, or when forming macroscopic aggregates in standard conditions (Aerts, 1999). And since entangled states are the vast majority of states, we have to conclude that the vast majority of our physical reality would be non-spatial.

It should be said, however, that it remains nowadays an uncommon view to consider that Bell's inequalities violations would be the consequence of correlations of the second kind, even though the latter are implicit in the quantum formalism. This means that the majority of physicists still consider that to explain these violations one needs to evoke some kind of influence-like mechanism. However, if influences are assumed to propagate in space, then they have to do so at a superluminal speed, and one can show that such speed must exceed that of light by at least four orders of magnitude (Salart et al, 2008; Cocciaro et al, 2011).

This possibility of superluminal influences is usually considered acceptable because quantum mechanics, in its standard formulation and interpretation, is protected from possible conflicts with relativistic causality by the so-called *no-signaling conditions* on quantum correlations (also called *marginal laws*), stating that the quantum probabilities have to obey certain specific relations, precisely preventing Alice and Bob to use their statistical data to communicate with one another at an effective superluminal speed.[2] However, in spite of the no-signaling conditions, a more attentive analysis shows that correlations resulting from influences propagating in space at a superluminal finite speed can always be exploited for obtaining faster-than-light communications (Coretti et al, 2011; Bancal et al, 2012). So, to use the words of the Swiss physicist *Nicolas Gisin* and collaborators (Bancal et al, 2012):

"*If we want to keep no-signalling, it shows that quantum non-locality must necessarily relate discontinuously parts of the universe that are arbitrarily distant. This gives further weight to the idea that quantum correlations somehow arise from outside spacetime, in the sense that no story in space and time can describe how they occur.*"

In other words, an explanation of quantum correlations in terms of

[2] See however Aerts et al (2019), for a general approach showing that a violation of the no-signaling conditions, in addition to Bell's inequality, is to be expected in joint quantum measurements, without this necessarily implying that a superluminal communication would be possible.

influences propagating in space, at some speed, seems to lead to an incurable conflict with relativity and to open the door to temporal paradoxes. So, either one remains in the uncomfortable position of not having an explanation for the entanglement phenomenon, or one accepts that it has to do with non-spatiality and with correlations of the second kind, that is, correlations relaying to a common cause which is not yet actual at the moment of a joint measurement but is actualized by it in an unpredictable way.

3 Superposition and non-spatiality

One might wonder at this point if non-spatiality would be an aspect of our physical reality that can only emerge when entities interact together and, as a result of their interaction, enter in a so-called entangled state. In other words, when electrons are not entangled, but in so-called separable states, can we consider them again as pure spatial entities, behaving as particles or waves (depending on the experimental context)?

To see that even this view is untenable, let us focus on a very specific property of quantum micro-entities, their *spin*, which is usually (although improperly) described as an *intrinsic angular momentum*, allowing the spinorial entity to behave like a *micro-magnet* (a *magnetic dipole*, with a north and south pole). There are many reasons why this image cannot be considered to be correct, and one is that the rotation should then be so swift that, if the micro-entity is considered to be a corpuscle with a given radius, its periphery would have to move at superluminal speed, in violation of the relativistic limit. But let us nevertheless consider that it would be possible to associate a direction in space to each spin state of an electron (or a neutron, etc.) i.e., that the idea that a spin would be a spatial-like property, describable as a micromagnet having a given orientation in space, would be essentially correct [regarding the problematic notion of spins' directions, see also Aerts & Sassoli de Bianchi (2015a)]. Then, in the same way a magnetic dipole, when rotated 360° (i.e., 2π), is brought back to the same state, one would expect that when the spin of an electron is rotated 2π, it is also brought back to the exact same state. But this is not what happens and in fact one needs to rotate a spin of 4π (720°) for it to be back to the same state.

This is not just a theoretical hypothesis but an experimental fact that has been verified in some beautiful experiments conducted in the mid-seventies of last century, not with electrons but with neutrons. Let us explain the rationale of these experiments, as they reveal a lot about the genuine non-spatial nature of micro-entities like neutrons, in a way that is totally independent from the previously described phenomenon of entanglement. Indeed, these experiments were performed using a single neutron at a time, which was made to interfere with itself in a way that corpuscular or wave-like entities are definitely unable to do.

These fundamental experiments were conducted by the groups of the Austrian physicist *Helmut Rauch* and of the American physicist *Samuel A. Werner* (Rauch et al, 1975; Werner et al, 1975), using a so-called *LLL device* made from a single Si-crystal [for a theoretical and conceptual analysis of these celebrated experiments, see Sassoli de Bianchi (2017)]. As described in Figure 7, this is a monolithic device consisting of three perfect crystal plates that are cut from a large and perfect *Si-crystal*. The size of the crystal is typically of *7 cm* and the thickness of its three plates is less than half a centimeter.

What is important to observe for our discussion is that the speed of the incoming (ultracold) neutrons, and the distance between them, was such that on average there was typically just a single neutron at a time passing through the device. Now, because of the geometry and orientation of the three parallel crystal plates, each time a neutron encountered one of them, it could only move along two distinct paths: one corresponding to the neutron being simply transmitted through the plate, without being deviated, and the other with the neutron being deflected by a given angle, due to the specific geometry of the internal structure of the crystal. In other words, at each encounter with a plate, there was a *bifurcation*, where the neutron could only take two different possible paths.

As described in Figure 7, this means that following the interaction with the three plates, a neutron could exit the LLL device along four possible distinct paths, with its presence being revealed by the corresponding four detectors D_1, D_2, D_3 and D_4. Two of these paths exit the device without interacting with the third plate (corresponding to detectors D_1 and D_4) whereas the other two recombine (i.e., *superpose*) exactly at the level of the third plate, finally also exiting the crystal towards detectors D_2 and D_3.

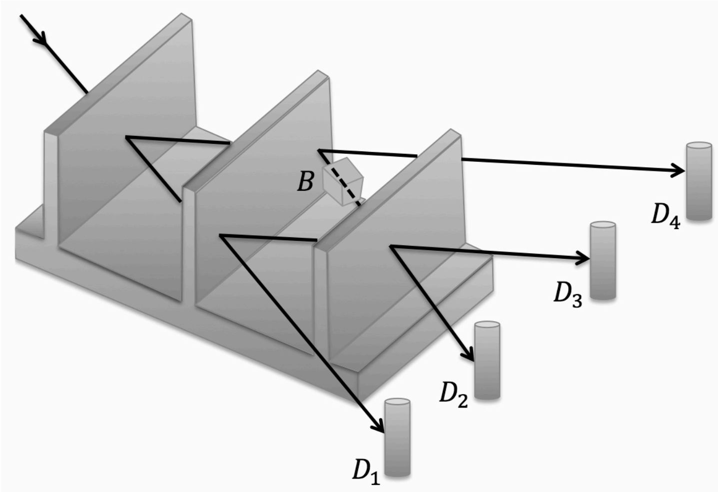

Figure 7 A sketch of the LLL silicon (Si) crystal interferometer, able to split the incident beam into four distinct beams, which are then detected by the four detectors D_1, D_2, D_3 and D_4. Along the path of one of the internal beams, a well localized static magnetic field B is applied, so as to rotate the neutron's spin of an angle that is proportional to the intensity of the magnetic field.

The idea of the experiment was to place a well localized (static) *magnetic field* along one of the two internal paths, so as to rotate the neutron's spin passing through it of a given angle, proportional to the intensity of the applied magnetic field. If neutrons (entering and exiting the LLL crystal one at a time) would just follow one, and only one, of the possible paths, the presence of the magnetic field would then not be able to affect the probabilities with which the different detectors click. However, since two of the internal paths recombine at the level of the third plate, quantum mechanics predicts that the associated *probability amplitudes* have to superpose, and since the action of the magnetic field is to shift the phase of the corresponding amplitude, a *phenomenon of interference* is expected to occur, proportionally to the rotation of the neutron's spin as induced by the magnetic field [things are in fact a bit more complicate and we refer to Sassoli de Bianchi (2017) for a more complete discussion].

Remarkably, what was observed, in accordance with the predictions of the theory, is that the intensity measured at the detectors D_2 and D_3 exhibited a 4π-*periodicity* with respect to the spin rotation angle (see Figure 8), thus demonstrating that only following a 720° rotation a neutron's spin entity is brought exactly into the same state, which is a property impossible to associate to any spatial entity like those we interact with in our everyday life.

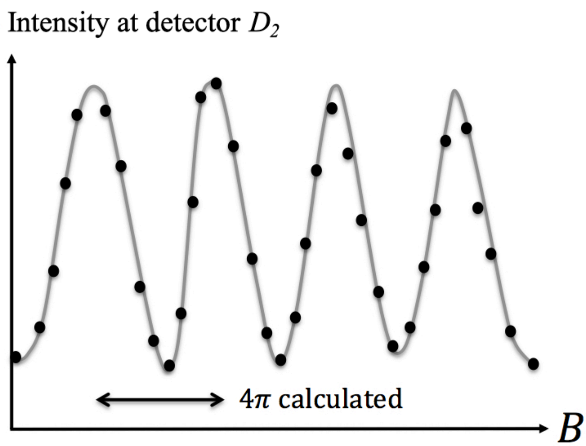

Figure 8 The data obtained by Rauch et al (1975), showing the typical 4π-periodicity of the intensity measured at detector D_2, when the strength of the applied magnetic field B, located on the upper internal path, is varied, so as to vary correspondingly the rotation angle of the neutron's spin, according to the phenomenon known as *Larmor precession*.

The experimental highlighting of this unusual 4π-symmetry of a neutron's spin, instead of the 2π-symmetry of an ordinary spatial object, as surprising and spectacular as it is, is certainly not the most amazing aspect that was evidenced in these experiments, when properly analyzed. To explain what we mean, it is useful to rescale the LLL crystal up to 25 million times and project it onto the European map [see also the discussion in Aerts (1999) and Sassoli de Bianchi (2017)]. As can be seen on Figure 9, neutrons then pass through the first plate in France, close to Paris, and once they have also traversed the second plate, the northern path crosses Denmark and Sweden, whereas the southern path goes over Poland and Lithuania, before both paths recombining in Latvia.

What is important to observe is that the neutrons used in these interferometry experiments have a so-called (longitudinal) *coherence length* that is typically of *one millionth of a centimeter*. When such length is scaled up 25 million times, one finds that the spatial region within which these imaginary (rescaled) giant neutrons can be acted upon, when they travel along their different possible paths, is a small cube of 25 centimeters! Comparing this with the hundreds of kilometers distance separating Sweden from Poland, it is clear that there is no way to interpret the neutrons entering the LLL device as extended spatial objects (as it would be the case if they were waves): they are truly more like small projectiles moving along very narrow paths.

Figure 9 A bird view of the LLL device, here scaled up 25 million times and projected on the European map.

But if this would be the case, then the 4π-symmetry of a neutron's spin could not be observed, as it requires the amplitudes coming from the two different paths, one traversing the localized magnetic field in Sweden, and the other one going over Poland (and thus not traversing the magnetic field) to superpose and interfere. If a neutron would truly be like a localized projectile, considering that just a single neutron enters the device at a time, then either it would encounter the magnetic field, if it takes the northern path, or it would not encounter it, if it takes the southern path. But in none of these two situations interference effects would be observed and the D_2 and D_3 detectors would just click on average the same number of times.

Consequently, we cannot say that a neutron is like a spatial well-localized corpuscle, moving on a single path, nor can we say that it is like an extended entity spread out in space, because its coherence length is very small and it can only be detected along very narrow paths, and never in the space between them. On the other hand, a neutron is able to jointly explore, or "sense," the different possible paths at the same time, something that a genuine spatial entity is obviously unable to do. In other words, these remarkable neutron interferometry experiments really force us to go beyond the wave-particle duality and accept that micro-entities, like neutrons, have a non-spatial nature, i.e., can be in non-spatial states, which however does not imply that they would not be influenced by spatial local apparatuses.[3]

Let us mention that in more recent times superposition experiments have been successfully performed also using much

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[3] Rauch's experiment alone cannot exclude the possibility of a spatial explanation *à la* de Broglie-Bohm, in terms of a wave *plus* a particle, both having a full physical reality; see for instance Vigier et al 1987. In an approach of this kind, the particle element is considered to be always perfectly localized in a specific path of the interferometer, whereas in the other path only a so-called *empty wave* would be travelling, the presence of which would then explain the interference effects. However, the hypothesis of empty waves was shown to be inconsistent in experiments performed by Mandel and collaborators (Zou et al 1992) and, generally speaking, approaches based on three-dimensional pilot waves will be unable to explain higher order (multiparticle) coherence effects. So, strictly speaking, Rauch's experiment provides support to the non-spatiality hypothesis only if additional experiments are also considered, eliminating alternative pilot wave-based (spatial) explanations. Note that Bohm himself was aware that a pure spatial picture of a pilot wave guiding the movement of particles would face serious problems when dealing with more than a single entity, as the *quantum potential* guiding their movement will then no-longer act in a three- dimensional Euclidean space, but in a configuration space of higher dimension (Bohm 1957).

more complex entities than neutrons, like large molecules, thanks to the advent of more advanced matter-wave interferometers and techniques for obtaining slow macromolecular beams. For instance, Gerlich et al (2011) were able to put molecular entities composed of 430 atoms (covalently bound together) into superposition states with respect to the "left arm" and "right arm" of their interferometer, with a path separation of about two orders of magnitude larger than the size of these molecules. Similar experiments were performed by *Sandra Eibenberger* and collegues, in Vienna, obtaining genuine quantum superposition states for giant molecules containing over 800 atoms (Eibenberger et al, 2013). All these experiments clearly show that the internal complexity of an entity that is brought in a state of spatial superposition is not at all affected by the process of delocalization, hence the idea that a superposition state would be akin to a 'spreading of the entity in a wave-like pattern over space' cannot be considered to be correct.

So, the question arises: How can we even imagine entities of this kind? Let us provide an example that the author heard the first time from *Constantin Piron*, when teaching his famous course of quantum mechanics in Geneva (Piron, 1990, Sassoli de Bianchi, 2017). Take a *10 € bill* (the original example was with 10 Swiss francs). When it is intact, we can certainly say that the *10 €* are located somewhere in space, like it is the case for an ordinary classical entity. More precisely, the location of the *10 €* is exactly the location of the *10 € bill*. But what happens when the bill is torn in two parts and the obtained pieces are spatially separated (see Figure 10)?

Clearly, when this happens, we cannot say anymore that the *10 €* are still located somewhere in space, although we cannot even say that they would have completely disappeared from space. Imagine for a moment that the two bill's fragments are placed into two different boxes. In a sense, we can say that the *10 €* are present in the two boxes, but it is also true that they are contained in none of them, which is very similar to the situation of a neutron that, in a sense, is simultaneously present in all its different possible paths within an interferometer, although it is also present in none of them. More precisely, when taken together, the two boxes certainly contain the *10 €*, but only in *potential* terms, which can become *actual* *10 €* only in the moment the two fragments are taken out from the boxes and joined together.

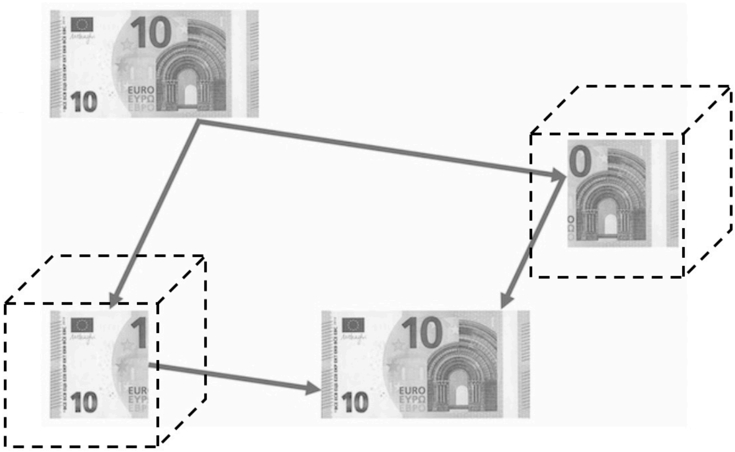

Figure 10 A *10 € bill* is first torn apart, then the two bill's fragments are moved on different paths (and for instance inserted into two separated boxes), to ultimately recombine at some other place in space. In the process, the *10 €* disappear from our spatial theater, to reappear again when the full bill is reconstituted.

This is of course only a metaphor, but a very revealing and interesting one, as it carries two crucial ideas. As we mentioned already, there is the idea that so-called quantum non-locality would be an expression of non-spatiality, where by the latter term one should not understand that a non-spatial entity would have necessarily totally disappeared from our spatial theater, as if this would be the case then it would become impossible to understand why a quantum (micro) entity can be easily influenced by classical (macro) entities, like the measurement apparatuses we use in the physics' laboratories, which are certainly stably present in space. In other words, micro-entities, like neutrons, although non-spatial, maintain a specific relation with space, in the sense that they always remain available in being detected inside of it, with a *degree of availability* that varies depending on the locations and their state of preparation. In the experiment with the neutron interferometer, there are only narrow paths where a neutron has a very high degree of availability in being "sucked" in space, whereas the degree of availability is very low for the regions in-between these paths. The latter are therefore sort of "interdimensional windows" through which one can act on neutrons and access their non-spatial reality.

Now, the reason why the *10 €* example works well with our intuition is that *10 €* are not just an *object*: they are also a *concept*. What we mean to say is that one has to distinguish the *10 € conceptual entity* from the *10 € bill objectual entity*. The *10 €*, as a conceptual entity, can be instantiated (that is, concretized, objectified) in many different ways. A full *10 € bill* is a possibility, but also *5 coins of 2 €* is a possible way of instantiating *10 €*, so using metal instead of paper, and of course we can also have *10 €* instantiated in an electronic way, as a specific transfer appearing in a given bank account. What is important to observe, in the case of the paper bill, is that when we affirm that the *10 €* are in the two separated boxes, and at the same time in none of them, this statement makes sense because two different *10 €* notions are jointly present in our mind. On one hand, there is the *10 € bill*, which is a concrete object, and as such is certainly not present in any one of the two single boxes (as just a piece of it is present in each box). On the other hand, there are the *10 €* understood as a more abstract conceptual entity, which as we observed can be instantiated in our spatial theater in many different ways. When we say that the *10 €* are simultaneously in the two boxes, we are more specifically referring to the *10 €* as an abstract entity that can be instantiated in different ways, in different contexts.

So, could it be that an entity like a neutron would be able to behave in the way it behaves because it is similar in nature to a human concept? In other words, could it be that the non-spatiality of the micro-entities is telling us that they would be like conceptual entities, which can manifest in different states, some very concrete, like those we can associate with spatial properties, and some more abstract, which we cannot associate any longer with spatial properties, and that this would explain their otherwise inexplicable behavior? Note that we are not saying here that quantum entities would be *human concepts*, what we are saying is that they would share with the latter a same *conceptual nature*, similarly to how an electromagnetic wave and a sound wave, although very different physical entities, do share a same undulatory nature (Aerts et al, 2018).

4 Indistinguishability and non-spatiality

Before spending some words on the possibility of ascribing a conceptual nature to the entities forming our physical reality, let us mention another quantum "strangeness," also directly pointing to the non-spatiality of quantum entities, and therefore also to their possible conceptual nature: *indistinguishability*. Spatial entities (think of a billiard ball) are strictly speaking always distinguishable, even when they are identical, that is, even when they possess the same set of properties (like a same mass, volume, charge, angular momentum, temperature, color, etc.). Indeed, assuming the *impenetrability* of two physical objects, i.e., that they cannot occupy at the same time the same location in space, it follows that they can always be distinguished by considering the different trajectories they follow in space. In a certain sense, each trajectory provides to each spatial entity a sort of label that allows one to distinguish it from the other entities having the same properties (see Figure 11).

So, spatial material entities can be identical and at the same time also remain always distinguishable, at least in principle, because they cannot possess at a given time the same spatial properties and the latter can always be used to set them apart. If entities, like say neutrons, would be like small marbles living in space, they would be distinguishable, and their distinguishability would play a role when they are assembled together, for example when forming the nucleus of an atom, or a giant (and extremely dense) entity called a *neutron star*, resulting from the collapsed structure of a giant star. Indeed, when identical quantum entities are brought together in regimes of temperatures where quantum effects are relevant, that is, when they can enter into stable entangled states, the fact that they are indistinguishable can produce drastic differences in their collective behavior with respect to the behavior of aggregates of classical distinguishable entities.

A gas of neutrons, which belong to the category of entities called *fermions*, different from a classical ideal gas made of distinguishable entities, will have for instance its pressure being only weakly dependent on temperature, instead of being directly proportional to it. Also, a gas of indistinguishable entities called *bosons* (like photons or helium-4 atoms), unlike a classical ideal gas is able to form a so-called *Bose-Einstein condensate*, when at very low temperatures the entire collection of entities truly behaves as a sort of single entity, entering in a condensate state that is tightly connected to remarkable phenomena like *superfluidity* (the possibility for a fluid to have *zero viscosity* and flow without any loss of kinetic energy).

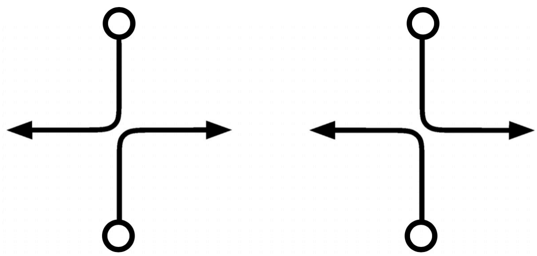

Figure 11 The situation of two identical billiard balls directed towards each other with equal speed, one from the North and the other from the South. Since they move in opposite directions, they will do the same after the collision and their speeds will also again be equal. If the collision is somewhat off-center, each ball will be deviated from its original direction of motion by some angle. Here two situations are described: on the left, the ball coming from North is deviated to the West, and consequently the ball coming from South is deviated to the East, whereas on the right it is the other way around. Clearly, only by discerning the trajectories of the two balls, during their collision, it is possible to know the direction towards which each one of them has been diverted to, hence distinguish the two situations. For quantum micro-entities, because of the absence of a notion of spatial trajectory, these two situations cannot anymore be distinguished.

All this is just to emphasize that indistinguishability can have remarkable effects and that these effects have been observed in laboratories. In fact, one of the experimental problems from which quantum mechanics originated, that of *blackbody radiation*, i.e., the problem of explaining the spectrum and intensity of the thermal radiation emitted by a non-reflective body as a function of its temperature, could only be properly addressed by considering that all photons involved in the energy exchanges are genuinely indistinguishable and therefore obey a quantum (Bose-Einstein) statistics, instead of a classical (Maxwell-Boltzmann) statistics.

More specifically, the difference between distinguishability and indistinguishability affects the statistical behavior of a collection of identical entities by affecting the way one has to count the number of their different possible configurations, which in turn depends on the fact that, when we exchange the role of two of them, this can have or not have an observable effect.

As a very simple example, take two entities A and B. If they are distinguishable at some level, then by exchanging their role this can have observable effects. For instance, assuming that the two entities can only be in two different states, let us call them ψ and φ, it is clear that the situation where A is in state ψ and B is in state φ is different from the situation where A is in state φ and B is in state ψ, so that these two possibilities must be counted separately. This means that when the two entities are distinguishable, there will be 4 different possible configurations for the composite system formed by them: the two we have just mentioned plus the configurations where the two entities are both in state ψ or both in state φ (see Figure 12).

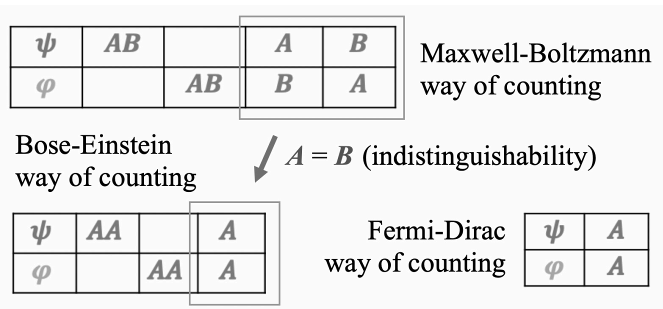

Figure 12 The number of possible states for a system formed by two (non-interacting) entities that can be individually in two different states, ψ and φ when (a) they are distinguishable individuals (spatial objects), corresponding to the Maxwell-Boltzmann way of counting; (b) they are indistinguishable individuals and are allowed to be in the same state (bosons), corresponding to the Bose-Einstein way of counting; (c) they are indistinguishable individuals but are not allowed to be in the same state (fermions), corresponding to the Fermi-Dirac way of counting.

But when the two entities are indistinguishable, we cannot say anymore that the situation where A is in state ψ and B is in state φ is a different situation than when A is in state φ and B is in state ψ, because now we have $A = B$, hence these two situations, or configurations, cannot anymore be distinguished. This means that the composite system only has a total of 3 different possible states and this different way of counting is characteristic of so-called *Bose-Einstein* (quantum) statistics (see Figure 12). This holds for the typology of indistinguishable entities having *integer spin*, called *bosons*, which are allowed to be all jointly in the same state. For the typology of indistinguishable entities having *fractional spin*, called *fermions*, there is the additional constraint known as *Pauli's exclusion principle*, saying that two entities cannot be jointly in the same state, so that just a single configuration remains in our simple example and we are in the situation where the way of counting is characteristic of so-called *Fermi-Dirac* (quantum) statistics (see Figure 12).

Micro-entities, be them fermions or bosons, are therefore certainly individuals, but mysteriously without any individual identity, as they appear to be truly and genuinely indistinguishable. This seems to go against Leibniz's famous ontological principle of the *identity of the indiscernibles*, stating that no two distinct entities can exactly resemble each other in all of their properties. But then, how can it be so? As we already emphasized, if we renounce considering a micro-entity as a spatial entity, then we cannot use anymore the notion of trajectory to attach a different spatial label to each member of a collection of identical entities. These however can remain different individuals because, even if totally indistinguishable, they do possess attributes that can be measured and used to count how many of them are present in a given system.

For instance, if the total *electric charge* of a collection of electrons is Q, then knowing that a single electron has an electric charge e, we also know that the collection contains a number $N = Q/e$ of identical electrons, and not a single electronic entity. But how can we understand then the nature of entities that are able to remain individuals and at the same time are also truly indiscernibles?

Take again the example of the *10 €*. No doubts that *10 €* describes a collection of entities, and more precisely that collection that is obtained by considering a combination of two concepts: the concept *10* (*Ten*) and the concept *€* (*Euro*), joined together in the combination *10 €* (*Ten Euro*). It is clear that all the euros in the combination are completely identical and all exactly in the same state, i.e., all carrying exactly the same meaning and value, so that we are truly in the presence of a collection of (here Bosonic-like) indistinguishable entities, and not of a single one. In other words, in the conceptual realm, quantum indistinguishability is not at all paradoxical but perfectly self-evident. But of course, the fact that *10 €* is a concept, and not an object, is essential for it being able to carry the (otherwise impossible to understand) quantum feature of *being many and at the same time being genuinely indistinguishable*.

5 A conceptuality interpretation

Considering that the example of the *10 €* works so well in describing both the possibility for an entity to be non-spatial and for a collection of entities to be indiscernibles, but nevertheless still remain individuals, one may wonder if this could be more than a clever metaphor and point to a deeper truth about our physical reality: that its building blocks would not be *object-like*, but *concept-like*. In other words, one may wonder if (1) quantum entities would behave similarly to human concepts because they share with them the same conceptual nature and, conversely, if (2) human concepts, as entities of a conceptual nature, would in return behave similarly to quantum entities, in the sense that *quantumness* and *conceptuality* would just be two different ways of speaking about the same reality.

Point (2) is in a sense less controversial than point (1), so let us start with it. The last two decades have seen the development of a new domain of investigation, called *quantum cognition*, which was pioneered by researchers like *Diederik Aerts*, *Andrei Khrennikov*, *Harald Atmanspacher* and collaborators; see for instance Busemeyer & Bruza (2012), Haven & Khrennikov (2013), Wendt (2015) and Aerts et al. (2013, 2016). Let us briefly explain the reasons why this field of study emerged. In the beginning of last century, during their investigation of the micro-world physicists were confronted with experimental data that were not explainable using the existing physical theories, in particular their logical and probabilistic foundations. It is precisely in their attempts of explaining the unexplainable that quantum mechanics emerged: a theory founded on a completely different (non-classical, i.e., *non-Kolmogorovian*) probability calculus. Something quite similar happened to cognitive scientists when they were confronted with unexpected data collected in the ambit of numerous tests conducted on groups of human participants, in order to study the probabilities characterizing their behaviors, or decision makings. Indeed, it emerged that in many circumstances human behavior would defy logic. In a nutshell, humans appear to be quite irrational.

As an example, we can describe the situation known as the *conjunction fallacy*, as evidenced in so-called *Linda problem* (Tversky & Kahneman, 1983; Morier & Borgida, 1984). Consider the following description of a person named Linda:

"31 years old, single, outspoken and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in antinuclear demonstrations."

Ponder then the following two statements: (1) Linda is today a bank teller; (2) Linda is today active in a feminist movement and is a bank teller. Which of these two statements appears more plausible to you? If your answer is (2), you have just fallen victim to the conjunction fallacy, as was the case for the average opinion of the tested subjects. Now, since the idea that the concomitance of two events is more probable than the occurrence of only one of them is in evident violation of the axiomatic rules of *classical (Kolmogorovian) probability theory* (which in turn is based on *Boolean logic*), experimental situations like those evidenced in the Linda's problem, and many others evidencing different logical fallacies, cannot be properly addressed by the latter.

This forced researchers to find a different paradigm in order to model, in a consistent and principled way, some of the accumulated data, and surprisingly the perfect choice appeared to be quantum mechanics. Well, maybe not so surprisingly after all, considering that the latter was equipped with all the needed conceptual and mathematical tools for dealing with all sorts of deviations from classical behaviors. Indeed, as we said, quantum mechanics also emerged in order to describe experimental situations which could not be explained using theories based on Boolean logic and the associated Kolmogorovian probability calculus.

It would be beyond the scope of this article to tell in a convincing way the story of quantum cognition, which by the way, to avoid possible confusions, has nothing to do with the notion of *quantum* *brain*, that is, with the speculation that quantum phenomena occurring in the brain at the micro-level would play a role in the way the brain functions, particularly in relation to the manifestation of consciousness and self-consciousness. In quantum cognition, one simply observes that quantum structures can appear at some organizational level of the mental activity, in the same way that it is possible to construct macroscopic quantum machines (for instance using elastic structures with specific geometries that can break in unpredictable ways) that are able to behave in a way that is very similar to micro-entities (Aerts et al, 2000, Sassoli de Bianchi, 2013a, Aerts & Sassoli de Bianchi, 2014).

In that respect, one should demystify the usual belief that a quantum behavior would be only the prerogative of micro-entities, being instead a form of organization that can be found at different structural levels within our reality (Aerts & Sozzo, 2015, Aerts & Sassoli de Bianchi, 2018). Of course, it is at the micro-level that this organization appears to manifest itself in the most remarkable way, thanks to the non-spatial nature of the micro-entities.

But also human concepts are genuine non-spatial entities, hence in the human conceptual realm their quantum-like behavior appears to be as fully explicated as that of the micro-entities, even though, of course, not all the remarkable symmetries that govern the physical microworld are also present in the much younger human conceptual domain.

Now, considering the huge success of quantum theory in modeling different cognitive situations, like those involving decision-making, conceptual reasoning, human memory and other cognitive phenomena, i.e., that human conceptual entities, when they interact with cognitive systems, appear to be very similar to the quantum entities interacting with measuring apparatuses, it became natural at some point, for one of the initiators of quantum cognition, *Diederik Aerts*, to ask and take very seriously the following question (Aerts, 2010):

"If quantum mechanics as a formalism models human concepts so well, perhaps this indicates that quantum particles themselves are conceptual entities?"

Aerts then formulated the following speculative hypothesis, which is today at the basis of the so-called *conceptuality interpretation of quantum mechanics* (Aerts, 2010):

"The nature of a quantum entity is 'conceptual,' i.e., it interacts with a measuring apparatus (or with an entity made of ordinary matter) in an analogous way as a concept interacts with a human mind (or with an arbitrary memory structure sensitive to concepts)."

In other words, according to Aerts' hypothesis, the elementary microscopic entities, which we know cannot be consistently described in terms of particles and waves (or even fields), would nevertheless behave as something very familiar to all of us, as we continually experience them in a very intimate and direct way: *concepts* (Aerts, 2009, 2010a, 2010b, 2013).

To help understand why such a hypothesis makes sense, we have to explain that concepts, like physical systems, can be modeled as entities that can be in different *states*, where a state has to be generally understood as an expression of what an entity is, in terms of its actual and potential properties in a given moment (Aerts et al, 2016), which can be described using different mathematical notions, depending on the specific formalism adopted. For instance, in quantum mechanics states are usually described by vectors belonging to a complex vector space, called *Hilbert space*.

The way a concept can change its state depends on the type of context with which it interacts. As a very simple example, consider the concept *Car* (we will use capital letters to distinguish abstract concepts from written words, which are the traces left by the latter on a given document). When considered in the context of itself, the conceptual entity *Car* can be said to be in its most neutral *meaning state*, sometimes referred to as the *ground state* of the concept. But it is also possible to combine the concept *Car* with other concepts. This is precisely what we humans typically do when we use our language: we combine concepts in order to create new meanings.

So, if *Car* is combined with *Fast*, say in the sentence *A Fast Car*, its state will not anymore be considered to be the ground state, but a different *"excited" state*. More precisely, when we go from *Car* to *A Fast Car*, the *Car* conceptual entity changes its state in a *deterministic* way. This is similar to what happens to the spin of a neutron when it passes through a magnetic field, also producing a deterministic change of its state that one can easily determine by solving the corresponding *Schrödinger equation*.

But to highlight the difference between two states, beyond considerations of a purely theoretical nature, one has to perform measurements, that is, one has to subject the conceptual entity to a given *interrogative context*, which in general will be *indeterministic*. For example, take two specific examples of cars, like a *Volkswagen Beetle* and a *Lamborghini Countach*. Then ask a group of people which one of the two best represents the more abstract concept *Car*. As it is not difficult to imagine, some people will choose the *Volkswagen Beetle* and others the *Lamborghini Countach*, and one can expect that both exemplars will be chosen with comparable frequencies, say 60% and 40%, respectively (see Figure 13).

Then take another group of people (or the same) and ask them the same question but this time in relation to *A Fast Car*. No doubts, almost all, if not all, will now select the *Lamborghini Countach* (see Figure 13). In other words, the *outcome probabilities* will change dramatically when using *A Fast Car* instead of *Car*, i.e., when we consider different states of the conceptual entity. The same is true when performing a measurement in quantum mechanics: different states will produce different probability distributions in relation to a given set of possible outcomes.

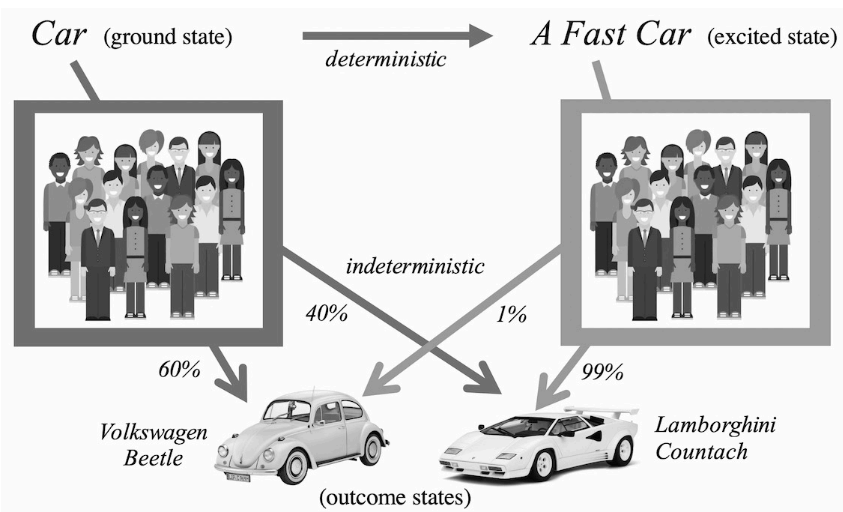

Figure 13 Different states of the conceptual entity *Car* will produce different outcome probabilities, when subjected to a given interrogative context, here consisting in determining which one of the two more concrete (outcome) states, *Volkswagen Beetle* and *Lamborghini Countach*, better represent *Car*, when the latter is either in its 'ground state' or in the 'excited state' defined by the combination *A Fast Car*.

Having said that, let us briefly describe some of the situations where the conceptuality interpretation allows one to better understand the strange behavior of the quantum micro-entities in a way that no other interpretations allows to do [for more details, we refer to Aerts (2009, 2010a, 2010b, 2013) and to the more recent review article Aerts et al (2018)].

Non-spatiality. Quantum entities are usually in non-spatial states because, being conceptual entities, they can be in states having different *degrees of abstractness* (or different *degrees of concreteness*), and only the most concrete (i.e., less abstract) states would correspond to those belonging to our spatial theater. For example, in the special case of human concepts, we can observe that the concept *Thing*, in its ground state, is undoubtedly more abstract than when in the state *The Thing Is A Car*, which in turn is more abstract than when in the state *The Thing Is A Car Called Lamborghini Countach*, which is more abstract than the state *The Thing Is A Car Called Lamborghini Countach That Is Owned By My Neighbor*. Clearly, this latter state of *Thing* brings the concept into close correspondence with the world of objects that belong to our three-dimensional space.

Heisenberg uncertainty principle. If quantum entities are conceptual, then they cannot be simultaneously maximally abstract and maximally concrete, which is none other than the uncertainty principle of Heisenberg rephrased in conceptual terms, now becoming perfectly self-evident. A neutron with a well-defined momentum would be a neutron in a maximally abstract state, whereas a neutron with a well-defined position would be a neutron in a maximally concrete state, and all states in between these two limit situations would be non-spatial states having an intermediary degree of abstractness (or of concreteness). In other words, there is a necessary *tradeoff* between abstractness and concreteness: the more we increase the former and the more the latter will decrease, and vice versa.

Entanglement. The mysterious non-spatial connections that are responsible for the creation of correlations in joint measurements, able to violate Bell's inequalities, would be nothing but *connections through meaning*. In other words, if the nature of the micro-entities is conceptual, then they are expected to spontaneously and systematically connect by sharing meaning, and since meaning connections are complex (multidimensional) abstract elements of our reality, this explains why they cannot be represented as simple spatial connections detectable in our three-dimensional theater. Note that Bell's inequalities can be easily violated when joint measurements are conducted in the psychological laboratories, on conceptual combinations that are adequately connected through meaning, thus giving further credit to the conceptuality interpretation of quantum entanglement; see for instance Aerts & Sozzo (2011) and Aerts et al (2018a,b).

Indistinguishability. Many conceptual entities, by combining with that particular category of concepts called *numerals*, will produce genuinely indistinguishable entities that still remain individuals. Hence, quantum indistinguishability becomes self-evident when quantumness is understood as an expression of conceptuality. Note that non classical (non-Maxwell-Boltzmann) statistics can be easily evidenced when considering certain combinations of words appearing in collections of documents.

Take for example the *Ten Animals* concept, which describes a collection of ten identical conceptual *Animal* entities. One can consider two possible states of *Animal*: *The Animal Is A Cat* (in short, *Cat*) and *The Animal Is A Dog* (in short, *Dog*). Then, one can perform counts, say on the Web, using a search engine like Google, to estimates the probabilities of finding these ten indistinguishable concepts in their different possible *Cat* and *Dog* states, like *Eight Cats And Two Dogs*, *Seven Cats And Three Dogs*, etc. Without going here into details, let us just mention that one finds in this way statistical behaviors that are quite similar to the Bose-Einstein one (with some added fluctuations), thus giving further credit to the conceptuality interpretation of quantum indistinguishability (Aerts, Sozzo & Veloz, 2015; Aerts et al 2018).

Quantum versus classical. According to the conceptuality interpretation, what we call objects are a limit situation of conceptual entities that can permanently remain in maximally concrete states. The best example of an object in the human conceptual realm or, to put it more precisely, of a concept that behaves similarly to an object, is what we call a *story*, i.e., a conceptual entity that is the result of a very large combination of different concepts all connected together through the "meaning fabric" of a specific narrative.

Without entering into the details, let us just mention the following interesting observation. Within the conceptual realm, concepts can be meaningfully combined using both the "and" and "or" logical connectives. If *A* and *B* are two concepts, then *A And B* and *A Or B* are also *bona fide* concepts. On the other hand, if A and B are two objects, then although 'A and B' can still be considered to be an object (the composite object formed by the combination of object A and object B), 'A or B' cannot be associated anymore with any object, but only with a concept, and this is one of the fundamental differences between concepts and objects.

The situation is similar for stories. In our human cultural landscape, we can find many stories that are of the form 'A and B', even when A and B are very long and complex stories. As an example, think of *book series*, which are big composite stories of the form 'A and B and C…" On the other hand, if A and B are two full-fledged stories, 'A or B' will usually not be associated with a genuine (meaningful) story within our human culture. Hence, stories behave similarly to objects and the notion of story allows one to understand how certain typologies of conceptual entities, formed by the combination of numerous elementary concepts, end up behaving in ways that are similar to the way objects behave.

For a further discussion of this subtle question, about the distinction between concepts and objects, see for instance Aerts et al (2018) and the references cited therein.

Open problems in physics. The conceptuality interpretation offers interesting insights into many open problems of modern physics, like the *measurement problem*, *quark confinement*, the existence of different *generations* of elementary particles, *dark matter*, the lack of evidence for *supersymmetry*, etc. For the exploration of these interesting issues, we refer the interested reader to (Aerts, 2009, 2010a, 2010b, 2013; Aerts et al, 2018).

6 Conclusion and perspectives

We started this essay by referring to Plato's and Abbott's allegories, suggesting that our spatial theater would be the expression of a very limited perspective. By means of some examples, taken from our investigation of the micro-world, we tried to make the case that there is some deep truth in these allegories. There is however also an important aspect that the latter were not able to capture, which is the following. When the higher-dimensional quantum entities are viewed from the limited perspective of our spatial classical representation, the process is never amenable to just an act of *discovery*. This is so because quantum observations, apart exceptional circumstances, cannot be understood as mere processes of discovery of pre-existing properties, but literally as processes of *creation* of properties that were just potentially existing prior to the observational process. To put it differently, when the higher-dimensional quantum realm is brought into manifestation within our spatial theater, the process is generally non-deterministic and of the symmetry breaking kind, i.e., a process where *the actual breaks the symmetry of the potential* (Aerts & Sassoli de Bianchi, 2017).

We also emphasized that our ancient construction of a spatial theater resulted from our perception of the macroscopic objects of our environment, mediated by our physical senses, particularly the working together – in a compatible way – of our senses of sight and touch (Aerts, 2014). However, when using more sophisticated measuring instruments in controlled experimental conditions, we were able to deepen our perceptions and observe that the behavior of the micro-entities is extremely puzzling, as their full reality was impossible to represent within the confines of a single spatial representation.[4]

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[4] Note that we can find (more or less explicit) traces of this impossibility in the ontologies of the different realistic quantum interpretations. For example, in Kastner's possibilistic transactional interpretation, it received the name of *pre-spacetime*, or *pre-empirical* layer (Kastner 2013, Aerts & Sassoli de Bianchi, 2017). In the Bohmian view, a related notion is that of the *implicate* (pre-spatiotemporal)

Thanks to the success of the emerging field of quantum cognition, it became however apparent that this strangeness of the quantum entities is probably due to the fact that we are using the wrong "image" when we try to capture their nature: we think of them in terms of *objects* instead of (non-human) *concepts*. In other words, if on one hand our senses have contributed to the illusion of a three-dimensional spatial world, formed by macroscopic objects, it is our more recent and abstract way of interacting with reality (more recent in terms of our evolution as a species on this planet), guided by language and meaning, which appears to be the one able to bring us closer to the deeper aspects of our reality, which are genuinely non-spatial and most probably conceptual in nature.

From the idea that the building blocks of our physical reality would be conceptual entities carrying meaning and exchanging it with the different pieces of ordinary matter, a natural *pancognitivist* view emerged (Aerts & Sassoli de Bianchi, 2018). This is however not a view to be understood in an anthropomorphic way, as is clear that human cognition is a very recent episode of formation of a conceptual structure, which took "place" in the ambit of a much more ancient evolutionary process, where everything within reality would participate in cognition.

Note that the mathematical language of our physical theories needs to be always accompanied by a suitable network of physical concepts, used to coherently relate the different mathematical entities and provide meaning to the portion of reality these theories are aimed to represent and describe (De Ronde 2018). Following the hypothesis of the conceptuality interpretation, one might be tempted to believe that human concepts would then be able to describe reality precisely *as it is*. This, however, would be an incorrect way to understand the message of the conceptuality interpretation, which requires to properly distinguish the human conceptual layer from that of the physical entities. We can certainly use our human concepts to try to represent and understand the (non-human) meaning that is vehiculated by the micro-physical entities and their combinations,

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order (Bohm 1957). And to give a last example, the infinite number of constantly branching spatial worlds of the many-worlds interpretation certainly cannot be represented within a single spatial representation, hence a many (spatial) worlds reality is again a non-spatial reality; see also the discussion in Aerts & Sassoli de Bianchi (2015b).

but this does not mean that the two conceptual layers can be considered to be equivalent as regards their meaning content.

In a sense, it is like learning a new language, belonging to an ancient alien culture about which we know nothing, as it developed in territories and times completely different from ours. Most of the concepts in the language of that extra-terrestrial culture will have no direct correspondence with ours, although this should not prevent us from trying to approximate their meaning by using suitable combinations of concepts that are today present in our language. However, nothing guarantees that our language will be sufficiently rich to faithfully represent every aspect of that alien culture, especially if the experiences and behaviors that gave rise to it are too different from those that gave rise to ours. In other words, generally speaking, when one language studies another language, there are no a priori reasons for the concepts contained in the former to coincide, or be similar, to those contained in the latter, particularly so if the two languages do not necessarily share the same origin.

In that respect, note also that in the conceptuality interpretation two lines of going from the concrete to the abstract are distinguished: a *parochial line*, which has more to do with the way we humans have abstracted concept from objects, in the course of our recent evolution on this planet, and what we believe is a more *universal line*, which is about observing how a large number of concepts can enter a more concrete state by combing in a meaningful way to form what we humans, in our culture, call "stories." These are of course subtle aspects of the conceptuality interpretation, still under investigation, which would require more detailed explanations, and for this we refer the reader to (Aerts et al 2018) and the references cited therein.

Coming back to *pancognitivism*, such a view has of course consequences also for our understanding of *evolution*. Indeed, if the nature of the physical entities is fundamentally conceptual, and if conceptuality and quantumness are just different ways to outline a same nature, then we need to adopt a much larger – quantum-like and conceptual-like – perspective not only on reality, but also on the mechanisms governing evolution. More precisely, adopting a quantum-like perspective on evolution means to understand the Darwinian natural selection account not only as a process of selection of properties that are already actual, i.e., already expressed within our spatiotemporal environment, but more generally as a process of selection through the actualization of properties that only possess a potential status.

In other words, evolution would be the result of more general forms of interaction than those usually considered, with the different evolutionary contexts exerting their influences (typically in a sequential manner) according to dynamics of the (weighted) symmetry breaking kind, where selection would be operated from a wider basin of possibilities (Gabora & Aerts 2005a,b; Aerts et al. 2011; Aerts & Sassoli de Bianchi, 2018).

Also, adopting a conceptual-like perspective means that the evolution of the different biological species would be much more like a *cultural evolution*. This means that our human culture, which appeared as a secondary evolutionary process following that of the biological species, would be part of a more ancient and primordial process of "cosmic cultural change," in force since the very beginning of our reality. This also means that it is not *Darwinian evolution* that should be considered the general model for cultural evolution, that is, for describing also epistemological and conceptual changes, but the other way around: it is cultural evolution, the processes of change happening at the conceptual, psychological and social levels around us, that might well represent our most advanced and general evolutionary model, also to be used to better understand our biological evolution as a species.

Of course, we are not saying that the Darwinian evolutionary mechanisms would not apply as such, but only suggesting that they should be reframed in a larger conceptuality-like picture, in the same way that classical physics had to be reframed within the ampler frameworks of quantum mechanics and relativity theory (Aerts & Sassoli de Bianchi, 2018).

As a closing thought, let us mention the *Fermi paradox*: the observation that intelligent life appears to be a rare phenomenon within our spatiotemporal theater, usually called the *universe*, despite of the fact that probabilistic estimates (for instance based on famous *Drake's equation*) would suggest the opposite. Of course, this could simply be due to the fact that the different forms of advanced intelligent life existing in the cosmos do not currently have great interest in being noticed by us, or simply that we have not taken sufficiently seriously, as a scientific community, the many unexplained sightings of presumed extraterrestrial (non-inert) objects of which the vast UFO literature is rich. But whatever the reason, we can also hypothesize that our three-dimensional material and spatial universe is in any case not the best place where to look for life and culture within our non-spatial reality. Quoting from (Aerts & Sassoli de Bianchi, 2018):

"Life and culture might indeed more abundantly be found not so much by exploring our universe in width, i.e., its spatial vastness, but in depth, i.e., exploring those regions that, from our spatiotemporal perspective, appear to be non-spatial and non-temporal, and in that sense more conceptual than objectual."

Remains the problem of learning how to explore reality not only *in width* (the outer space, as typically explored by the *astronauts*), but also *in depth* or, better, how to further the "in depth exploration" that we have just initiated. Are we condemned to contemplate the much broader non-spatial reality by remaining forever confined within our three-dimensional spatial theater, that is to say, by only taking a peek through the quantum and relativistic windows, without ever stepping over it, or will we be able one day to unlock new possibilities and promote actual "inner space" explorations? This is a question to which it is impossible to provide any satisfactory answer today, but on which it is certainly possible and useful to meditate.

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AutoRicerca

Multiplex realism

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Abstract

According to the view of *multiplex realism*, which will be presented and motivated in this article, our three-dimensional Euclidean theater is only one among many theaters that can be conceived and constructed, to stage the whole of our reality. The view of a 'multiplex reality' has consequences not only for our understanding of the nature of the physical world, particularly when we consider the relation between classical and non-classical (quantum and relativistic) entities, but also for our understanding of the manifestations of consciousness.

1 Introduction

As an evolving species, we have been present for hundreds of thousands of years in a very special niche of our reality: the crust of our beautiful planet Earth, surrounded by very special physical entities. From our multiple interactions with these entities, which we experienced by means of our dense bodies, we started, a long time ago, the construction of a prototypical *worldview*, in the attempt to order our experiences into a consistent *map of relations*. From this pre-cultural and pre-scientific construction, a first *clothing and decoration* of our reality resulted, allowing us to identify those portions of it that were recognizable as *aggregates of sufficiently stable properties*, where by 'stable' we mean that these properties could remain *actual* for enough time, thus becoming easy to observe. These *clusters of relatively permanent properties* (think of a material entity having a given size, weight, etc.) are what are called today, in physics, *classical entities*, or *macroscopic objects*, which include the astronomical bodies that we can see moving in the sky, like the Moon and the Sun, obeying with good approximation the laws of non-relativistic classical mechanics.

We can distinguish (at least) two different *directions of penetration* in our process of clothing and decoration of reality. One direction, which we have just mentioned, is a *penetration in depth*, through which we have identified those phenomena that, according to our senses, particularly those of sight and touch (Aerts, 2014), stood out compared to others, because of their *availability* in interacting with our body and becoming part of our experiences, and because such availability persisted long enough, allowing us to have multiple experiences with them. In other terms, by means of our penetration in depth of reality, we have recognized the existence of *experientially separated and stable* portions of it, today called, as we said already, classical entities.

The second, in a sense complementary, direction of penetration, can be called *penetration in width*. It corresponds to our effort to organize the content of our experiences with all these different *aggregates of stable properties*, i.e., with the different physical entities that appeared to us to be separated, in the sense of not influencing each other in a significant way. This process of penetration in width, through which we have identified the more important and evident relations among these entities of our ordinary experiences, can be understood as an *ordering process giving rise to a space*. And since, apparently, most of our practical experiences were with classical entities, the *space of relations* that emerged from such penetration in width is what we call the *three-dimensional Euclidean space*. In other terms, *space* can be essentially considered as *a very specific theater of reality that emerged when a given set of experiences was properly ordered and organized* (i.e., put in relation to each other). In this view, the three-dimensional Euclidean space should not be imagined as an external and immutable container accommodating the different possible classical entities (following Newton's substantivalist view), but really as the manifestation of a *structure emerging from their relations* (in agreement with Leibniz's relationism), which in turn also depends on the very specific "way of interacting" we have focused on, in our initial process of penetration.

The reason why a specific *theater of reality*, which we have *constructed* during our long process of penetration first in depth and then in width of reality, has been mistaken, over time, for a fundamental substantive container for the latter (a position still maintained today by the majority of scientists) is easy to understand: as time went by, we have simply forgot about our construction, and since the typology of our experiences remained essentially the same, it was easy and natural to start believing that all of our reality should necessarily fit into such theater, so that the theater and its content, and reality, would just be one and the same thing. This belief, however, becomes difficult (if not impossible) to maintain when, for whatever reasons, new experiences are accessed, i.e., new entities, different from those that were discovered in our initial process of penetration, become suddenly available to be experienced, in a direct or indirect way, and because of their radically different nature, they do not let themselves be included in the relational space that we have built thus far. Also, if the construction of this relational space is such that no natural extensions of it can be conceived, that is, if the construction produced a sort of *closed environment*, in accordance with Heisenberg's notion of *closed theories* (Bokulich, 2008), then we will simply fail to incorporate these new entities and their new relations in the existing representation. Accordingly, they will be considered *non-spatial entities*, i.e., strange entities that although we cannot deny their existence, they nevertheless remain not permanently or fully representable (and therefore not permanently or fully present) in our Euclidean spatial "container."

Note that when we speak of new experiences, we do not necessarily mean that they must be new in a strict chronological sense. These experiences may actually be extremely old, if we consider when the corresponding elements of reality were available to us for the first time. However, what matters is if they were taken into consideration or not in our process of penetration, i.e., in the construction of an *intersubjective experiential space*, consensually shared by all human observers and participators of reality, or labeled as mere *anomalous experiences*, with no clear relation with the other experiences, so that they remained essentially without a dedicated place in the theater under construction, for instance because of their *ephemeral nature* (Sassoli de Bianchi, 2011), their *rarity*, or because not everybody was equally able to access them.

It may happen, however, that some of these non-ordinary experiences suddenly become more accessible, or obtain more attention, so that not only will there be an urgency to explain them, but also to find their mutual relations and, if possible, their relation with the entities that have already received a place within the current theater, i.e., with the entities that we usually associate with our ordinary experiences. Of course, the first attempt will always be that of trying to represent these new *non-ordinary entities* in the already existing representation, which in our discussion we have identified with the three-dimensional Euclidean space. However, as we mentioned, this attempt may turn out to be unsuccessful, because the nature of these non-ordinary entities may be too different to allow their inclusion into it, or even in an extended version of it. As we are going to explain, two paradigmatic examples of entities that have spoiled our efforts to incorporate them into our classical theater are the 'human conceptual entities', the 'quantum entities' and the 'relativistic entities'. This, probably, is not a coincidence, but a consequence of the fact that quantum (and in part also relativistic) entities, when viewed from a certain perspective, reveal a *conceptual nature* (although a non-human one).

2 Entanglement

As a paradigmatic example of a breakdown of our Euclidean theater construction, we can consider the discovery of so-called *entangled states*. At the theoretical level, they were initially discussed by *Einstein*, *Podolsky* and *Rosen* (1935), and by *Schrödinger* (1935), and their existence has now been firmly established in many experiments, for instance in the historical ones performed by *Alain Aspect* et al. with photons in 1982 (Aspect et al, 1982, 1999). The reason why entanglement is incompatible with our Euclidean construction is very simple to understand. As we said, during our 'penetration in width' of reality we have constructed a spatial representation of the different possible relations between the entities that we could identify, by means of our 'penetration in depth'. In this representation, the notion of *spatial distance* has been used to quantify the *separation* between the different entities, where the term 'separation' must be understood in the *experimental* sense. The idea is that the better an entity X is *experimentally separated* with respect to another entity Y, the greater is their Euclidean spatial distance $d_e(X, Y)$.

Being *experimentally separated* means that when we test a property on entity X, the outcome of the test will not depend on other tests we may perform (simultaneously or in different moments) on entity Y, and vice versa.[1] For ordinary (classical) entities this is guaranteed if the spatial distance separating them, and the time interval between the different tests, is such that no signal can propagate in time between the two entities, to possibly influence the outcomes of the respective tests; and in the limit where the two tests are performed in a perfectly simultaneous way, any finite distance is in principle sufficient to guarantee that we are in a *non-signaling condition*, i.e., in a situation of full experimental separation.

So, 'spatial separation' and 'experimental separation' were considered to be synonyms, as the former was precisely used to represent the latter, during the construction of our Euclidean theater. As an example, consider two objects, A and B, moving in opposite directions, and two experimenters jointly measure their respective positions and velocities. In general, there will be no *correlations* between the outcomes of their measurements, because the two entities are spatially separated, and therefore perfectly *disconnected*. This is a necessary but not sufficient condition, as there are situations where even though two entities are experimentally separated, i.e., disconnected, their properties can nevertheless be correlated. For this, it is sufficient that the two entities were connected in the past, and have been disconnected by some physical process, in such a way that the process of disconnection *created correlations*.

Take a rock initially at rest, say at the origin of the laboratory's system of coordinates, and assume that at some moment t_0 it explodes into two fragments A and B, of equal masses, flying apart in space (see Figure 1). The positions and velocities of these two fragments of rock will then be perfectly correlated, due to the conservation of momentum, i.e., if the position and velocity of fragment A, at a given subsequent instant t_1, are x and v, then the position and velocity of fragment B, at the same instant t_1, will be $-x$ and $-v$. Such perfect correlation, however, does not describe a situation of a persisting *interconnection* between the two fragments, being a simple consequence of the fact that the two fragments were previously part of a single whole entity.

[1] It will not depend on them in an ontological sense, rather, possibly, in a dynamical sense, for instance because both entities may interact by means of a force field, such as gravitational or electromagnetic fields.

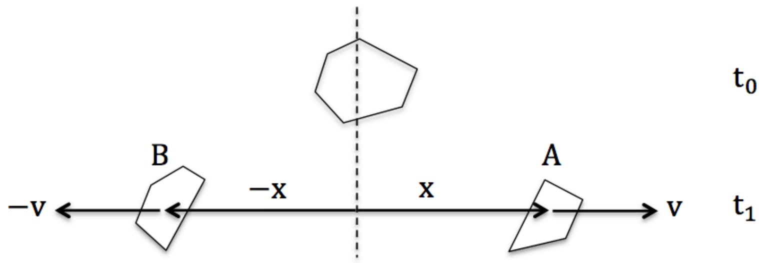

Figure 1 A rock initially at rest, explodes into two fragments of equal masses, flying apart in space.

In other terms, we have to distinguish between correlations that are already present in a bipartite system resulting from previous processes of connections-disconnection, which therefore can only be *discovered* during our observations, from correlations that are literally *created at the moment of their observation*, i.e., which are created out of an *actual connection* between the two parts of the bipartite system when these two parts are subjected to a measurement. This distinction is fundamental, and so it was proposed in 1990 to name the correlations that are only *discovered* in a measurement, '*correlations of the first kind*,' and those that instead are *created* in a measurement, '*correlations of the second kind*' (Aerts, 1990).

The important role played by the famous *Bell inequalities* (Bell, 1964, 1971), among other things, is precisely that of allowing one to distinguish between correlations of the first kind and of the second kind. Indeed, only the latter can violate Bell's inequalities (Sassoli de Bianchi, 2013a). However, contrary to the misconception that is still widespread among physicists, the violation of Bell's inequalities is not a specificity of quantum systems, as also classical macroscopic systems can easily violate them. This is so because, as we said, what truly matters for their violation is to deal with correlations of the second kind, created during the very process of measurement. But to create correlations one only needs the two entities forming the bipartite system to be *connected* in some way, and for classical (ordinary, macroscopic) entities a connection can easily be realized by creating a contact between the two entities, which can be direct or mediated by a third entity. As an example, imagine two identical dice connected through space by means of a rigid rod whose two ends are glued to the center of the dice's opposing faces. It is then easy to show that, because of the presence of the connecting rod, the double-die system becomes entangled, and correlations can be created in specifically designed coincidence "rolling measurements," able to maximally violate Bell's inequalities (Sassoli de Bianchi, 2013b, 2014).

Why, then, did Einstein call the quantum correlations produced by entangled entities, "spooky actions at a distance," when classical entities can easily produce quantum-like correlations, i.e., correlations of the second kind, violating Bell's inequalities? The answer is straightforward and brings us back to our discussion of the intrinsic limits of our Euclidean theater. A rod connecting two dice is clearly an element of reality that we can still represent within our three-dimensional Euclidean space, but the element of reality that establishes a connection between two microscopic quantum entities (like two photons, two electrons, etc.) in an entangled state cannot. So, the "spookiness" of the quantum correlations comes from the fact that: (1) they are not of the first kind and (2) the connecting element out of which they are created cannot be represented in our Euclidean theater. To describe this puzzling situation, physicists have used the term *non-locality*, but we think such a term is unfortunate, as it hides the essential nature of the phenomenon, which is the consequence of the existence of *non-spatial connections*, i.e., connections 'not happening in space'.

3 The EPR paradox

If it is correct to say that the observed correlations between entangled microscopic entities emerge from the existence of non-spatial connections, is it possible to extend the construction of our classical theater, for instance by adding more dimensions to it, to also include these new pure quantum elements of reality, which thanks to our modern laboratory experiments have recently discovered? Also, can we say that the quantum formalism has provided us with a more precise and encompassing description of the different entities forming our reality and their relations? Could we replace the classical Euclidean theater with some form of *quantum theater*, to represent all possible physical entities, their properties and mutual relations? Furthermore, can we incorporate the classical description into the quantum one? Of course, the answer to these questions will depend on how exactly we understand the terms 'quantum' and 'classical'. But let us give an example of what we think is a fundamental difference between the classical and the (standard) quantum formalisms, which make their associated 'theaters of reality' in a sense incommensurable. This example comes from the well-known (but not for this, we think, fully appreciated) situation called the *EPR paradox*.

In 1935, *Einstein* and his two collaborators, *Podolsky* and *Rosen* (a triumvirate we will designate by the acronym EPR) devised a very subtle *thought experiment* to highlight a possible inadequacy of the quantum mechanical formalism, in the description of the physical reality (Einstein et al, 1935). The reason their thought experiment was qualified as a paradox is that the predictions of quantum theory, regarding the outcomes of their proposed experiment, differed from those obtained when reasoning according to a very general *reality criterion*. If asked about the EPR paradox, most physicists will say that it has been solved by the mentioned *coincidence experiments* conducted on pair of entangled photons in singlet states, realized by *Alain Aspect* and his group in 1982 (Aspect et al, 1982), and which have been reproduced by many authors, with different quantum entities, under always better controlled experimental situations (Aspect, 1999; Hensen et al, 2015). Additionally, most physicists will say that these experiments contradict EPR's reasoning, in the sense that they confirmed the exactness of the quantum mechanical predictions. And this, of course, has considerably strengthened the general confidence of physicists regarding the completeness of the standard quantum framework, along with the fact that quantum mechanics would be the ultimate theoretical ambit within which all descriptions, laws, and experimental operations would need to be formulated in.

This conclusion, however, is the fruit of a misconception regarding the true nature of the EPR paradox, which had actually not been solved by experiments like those conducted by Aspect, but which can be solved by means of a simple, although quite subtle, mathematical reasoning (Aerts, 1981, 1984). This solution, however, says exactly the opposite of what is generally believed to be true: *the quantum mechanical description of reality is incomplete*; *we cannot straightforwardly incorporate a classical theater into a quantum one*, at least not if quantum theory is understood in its conventional sense. This also means that EPR were right in considering quantum theory incomplete, although the reason for its inadequacy was not what they thought. Now, since this result remains, in our view, exceedingly unknown, in the present and subsequent sections we will briefly explain its logic in the simplest possible terms, as this will also strengthen our proposal of putting forward a new view of realism, which we recently proposed to call *multiplex realism* (Aerts & Sassoli de Bianchi, 2016a), which consolidates what we currently know about the complex and multidimensional structure of our physical reality.

Let us start by reviewing what EPR did in their celebrated article (Einstein et al, 1935). First, they introduced the important notion of *element of reality*, by means of the following definition: "If without in any way disturbing the state of a physical entity the outcome of a certain observable can be predicted with certainty, there exists an element of reality corresponding to this outcome and this observable." This is one subtlety in the whole EPR reasoning which contains a very deep insight into the nature of reality: *that something real is there if one can predict it through an experiment which can be executed without disturbing the state of the entity in question*. Then, EPR considered the situation of two quantum entities that interacted and subsequently flew apart in space, thus becoming spatially separated and, according to EPR, also experimentally separated. The third step taken by EPR in their paper is to consider the quantum mechanical description of this situation, which they calculate in explicit terms, in accordance with the notion of entangled states, from which it can be seen that the positions and velocities are necessarily correlated, in the sense that, as was the case for the two aforementioned rock fragments, if one of the entities is observed to have position x, the other will certainly have position −x (taking always the origin of the system of coordinates as the place where the entities interacted before flying apart), and if one of the entities is observed to have velocity v, the other one must certainly have momentum −v.

Now comes the truly subtle part of the EPR reasoning: they considered the situation where one could eventually measure the position of one of the quantum entities, let us say entity A, flying to the right (entity B then flying to the left). Suppose that such a measurement of position was carried out, and the position of entity A would be registered, for example as x. Then, according to the quantum description, it follows that the position of entity B can be predicted with certainty and is −x. Overall, this means that a measurement can be performed (the measurement of the position of entity B) that does not disturb the state of entity B (since the two entities are spatially separated, and therefore are also assumed to be experimentally separated) and predicts the position of entity B (position −x).

The same reasoning can be made for the velocity (or momentum), measured on entity A, which we will assume was found to be v. Similarly to the case of measuring position, the quantum description predicts that the velocity of entity B must then be −v, which means that again a measurement can be made that does not disturb the state of entity B and makes it possible to predict with certainty the value −v for its velocity. But this means that both values of position and velocity can be predicted for entity B by means of measurements that do not disturb its state. Consequently, according to the aforementioned and very general reality criterion, both position and velocity can be said to have simultaneous definite values (−x and −v in the situation considered), which is clearly in contradiction with *Heisenberg's uncertainty relations*. Hence the paradox, and the EPR conclusion that quantum mechanics is an incomplete theory, as it cannot represent all the genuine elements of reality of a physical entity.

As is known, Bohr's reaction to the EPR argument was quite obscure. He said that one "is not allowed in quantum mechanics to make the type of reasoning proposed by EPR, and more specifically, the notion of element of reality does not make sense for quantum mechanical entities" (Bohr, 1935). The authority of Bohr and the general influence of the Copenhagen interpretation resulted in the majority of leading quantum physicists (with the notable exception of *Schrödinger*) accepting that there was not really a deep problem involved in the EPR paradox. Later, perhaps under the influence of *David Bohm*, who certainly took the EPR argument seriously (and invented the entangled spin example as a new and more transparent description of the EPR-like situation), a small group of physicists, among whom was *John Bell*, believed that EPR highlighted a fundamental problem in quantum mechanics related to its possible incompleteness. However, different from what EPR, Bohm, Bell and others believed, the incompleteness in question was not an issue of 'providing additional variables' to make it complete, or more complete, but a question of a much more severe shortcoming, related to the *impossibility for the quantum formalism to describe experimentally separated entities*.

4 The solution of the EPR paradox

To explain why this is so, let us start by emphasizing a point in the EPR reasoning that is usually overlooked: their reasoning is an *ex absurdum* one. Indeed, what EPR proved is that 'if quantum mechanics is a correct and complete theory', then it follows that 'it is an incomplete theory'. This is so because in their analysis they use quantum mechanics to describe the situation of two *separated* quantum entities A and B, flying apart following their interaction, assuming that the quantum description would be correct and complete, in the sense that it would accurately describe such situation. Now, even if the reasoning is *ex absurdum*, it is definitely possible to draw a conclusion from it when a contradiction is reached, and the conclusion is always that one of the premises of the reasoning must be false. So, by proving that if 'quantum mechanics is correct and complete' then 'quantum mechanics is incomplete', one can conclude that either (1) 'quantum mechanics is incorrect', or (2) 'quantum mechanics is incomplete'. Suppose for a moment that we exclude the possibility that quantum mechanics would be incorrect, as this was not at stake at the time of the EPR paradox, then the only possible conclusion is that quantum mechanics would be incomplete, and that is the reason why one can claim that the EPR reasoning proves, under the hypothesis that quantum mechanics is correct, that quantum mechanics is incomplete.

But, as we said, the status of this conclusion is that of a proof *ex absurdum*, and we know that we cannot attach any truth-value to the intermediate steps of a proof *ex absurdum*. This means that the step in the EPR reasoning saying that quantum mechanics has to be supplemented with additional variables has per se no truth-value at all. In other terms, it is incorrect to say that quantum mechanics is incomplete *and* needs to be supplemented with additional variables to solve its incompleteness. Indeed, the EPR reasoning does not offer any hint about what the nature of the incompleteness that it reveals would be. This is a point that has been overlooked by the majority of scientists studying the EPR paper, just as EPR were probably not aware of the '*ex absurdum* status' of their incompleteness proof. The forgoing reasoning makes it easy to understand why one of us, when trying some decades ago to elaborate a mathematical framework for the general description of separated quantum entities, was able to view the EPR work from a completely new angle. Indeed, while describing the situation of *bipartite systems formed by two separated quantum entities*, it was possible to prove, this time in a constructive way (not by a reasoning *ex absurdum*), that quantum mechanics was unable to describe this very simple situation.

This can be interpreted as an incompleteness of quantum mechanics (or incorrectness) and hence, it illuminates the origin of the contradiction identified by EPR in their reasoning. The situation is that: *quantum mechanics is an incomplete theory as it cannot describe the situation of separated quantum entities*, and since in the EPR reasoning quantum mechanics is used to describe a situation of quantum entities having interacted at a certain moment and flown apart, *which are then assumed to behave as separated quantum entities*, this necessarily leads to a contradiction. At first sight, as we explained, the contradiction identified in the EPR reasoning may suggest that one would need to introduce additional variables to allow position and velocity to have simultaneous definite values and escape the limitation of Heisenberg's uncertainty relations. But, a more careful analysis of the reasoning shows that this conclusion is incorrect, as the *ex-absurdum* reasoning does not allow one to deduce that that the introduction of additional variables (associated with the states of the two entities under investigation) would remedy the incompleteness.

Now, one could say: "All right, I follow your argument, and the conclusion that the nature of the incompleteness of quantum mechanics, already touched by the reasoning *ex absurdum* in the original EPR paper, would be the impossibility for the standard quantum formalism to describe separated quantum entities. But, have not EPR-like experiments, like those performed by the group of *Alain Aspect*, precisely shown that, in the situation considered by EPR, quantum mechanics does actually provide the correct description of two quantum entities flying apart, after having interacted? And since the experiments have shown that Bell's inequalities are violated, in accordance with the quantum predictions, doesn't this mean that quantum theory does actually correctly model the situation?"

The answer is both yes and no, hence some additional explanations are needed. At the time that EPR proposed the example of two quantum entities that have interacted and then flown apart, it was quite natural to expect that their spatial separation was equivalent to their experimental separation, i.e., that two entities, being spatially separated, were by definition also disconnected, i.e., experimentally separated (in accordance with the logic of our ancestral 'penetration in width' process). This expectation, however, has been overruled by many experiments, showing that, by making a big effort and by taking all sorts of precautions, one can indeed create experimental situations where microscopic entities, after having interacted, can remain interconnected (i.e., experimentally non-separated, entangled) even though arbitrarily large spatial distances separate them.

The possibility of producing these non-local/non-spatial states is remarkable and was totally unexpected, as it wasn't part of our previous construction of the Euclidean theater. It is however important to understand that it has very little to do with the EPR reasoning. Indeed, EPR, assumed that two quantum entities, when flying apart following their interaction, end up separated instead of remaining interconnected, as their *ex absurdum* reasoning can only be applied on such separated entities. Now, without diminishing the importance of the discovery of non-local/entangled states which open a window to a larger non-spatial reality impossible to fit into our three-dimensional theater, one has to understand that, in principle, experiments could also be done where instead of making a big effort to preserve the entanglement (i.e., the connection) when the two entities fly apart, an effort could be made to obtain the opposite situation: where two entities become disentangled when they fly apart.

Experiments of this kind have never been made consciously, because nobody realized that these would be the situations leading to the EPR paradox, i.e., that the incompleteness of quantum mechanics is not revealed in the physical situation of quantum entities flying apart and remaining non-separated, as these are the situations which are well described by the quantum formalism (as the violation of Bell's inequalities unequivocally proves), and there is no contradiction (no paradox) in this case. However, most of the EPR experiments that are usually interpreted as 'badly performed experiments' are certainly able to produce a disconnection in quantum entities flying apart, and these are precisely the situations that quantum mechanics is unable to describe.[2]

5 Multiplex realism

The experimental observation of quantum entangled states (by means of the violation of Bell's inequalities), and our logical analysis of the content of the EPR paradox, tell us two important things about our construction of a stage for the physical entities populating our reality. First of all, quantum entanglement demonstrates that they can remain interconnected even though arbitrarily large spatial distances separate them. This means that quantum entanglement cannot be fully represented in our Euclidean space, precisely because the reality of the connection it subtends cannot be associated with anything 'existing in space between the two entangled entities', i.e., with anything that would 'unite them through space'. In other terms, the classical Euclidean theater is too limited to stage the whole of the physical reality that we have been able to detect so far, by means of our instruments.

As we have explained already, we can understand this inadequacy by considering how special our human 'intraphysical condition' is, resulting from our manifesting, as consciousnesses, through our macroscopic and relatively dense vehicle of manifestation; a situation that has for instance been suggestively described by Plato in his famous *allegory of the cave*. The question, then, is: considering the newly discovered "quantum cave," as described by the mathematical structure of quantum mechanics, is it a more encompassing realm, containing in its interior the classical one, or is it, instead, just another cave, one certainly not directly inhabited by us humans, but one that is also the expression of a specific and necessarily also limited perspective on reality?

If we take seriously the content of the EPR paradox, and its solution, we see that the quantum cave also has its shortcomings. Indeed,

[2] Technically speaking, the reason for this is that there are properties of a system formed by two separated quantum entities that cannot be represented by orthogonal projection operators; see Aerts (1981, 1984).

in the same way as quantum entanglement cannot be represented in the classical cave (or theater, we shall use the terms 'cave' and 'theater' as synonyms), experimentally separated entities are also impossible to be described in the quantum cave. In other words, in the hypothetical world described by quantum theory, everything is inextricably interconnected and non-separable, but according to our experience with ordinary macroscopic entities, we definitely know that separation is also a possibility; it is, in fact, what was considered to be the rule before the advent of quantum physics (a rule that is incorporated in our construction of the Euclidean space).

So, if we want to remain prudent, all we can say so far is that different caves/theaters possibly exist, associated with the different vantage points that can be adopted on reality, and that in a sense reality is a construction about different possible representations. In other terms, as investigators/participators of reality, our work would not be only that of identifying the content of the theater we inhabit (and have created), and of the other possible theaters, but also the relations (the *partial morphisms*) existing between their different elements of reality, which we cannot *a priori* expect to be all representable/contained in a single and all-encompassing stage (although this remains a possibility we cannot logically exclude), as elements of reality belonging to one theater may not always find their equivalent in another one.

Most physicists still believe today that the quantum theater does contain the classical one, but as we explained we can cast serious doubts on that, as quantum mechanics cannot describe entities that are separated in experimental terms, whereas we can certainly experience plenty of separated entities in our classical theater. Also, there are elements of reality that appear to be of a genuine intermediate nature, like for instance those describing some of our human cognitive processes (more will be said about them later in the article), which cannot be conveniently represented neither in the classical nor in the pure quantum theater, as they seems to belong to a truly intermediate representation (Aerts & Sassoli de Bianchi, 2015a,b). Also, the failed tentative to unify gravitational and quantum elements of reality, within a unique, bigger and coherent representation, could very well be due to the fact that, for structural reasons, a single 'quantum plus gravitational' theater may simply not be possible to construct.

We have called the view we are putting forward in this article *multiplex realism* (Aerts & Sassoli de Bianchi, 2016a). This view gives due importance to the fact that we have been present for hundreds of thousands of years on the surface of our planet Earth, surrounded by material objects obeying with good approximation Newton's laws, that we have consequently staged in a Euclidean theater that we have expressly constructed to suitably describe our relations and interactions with these classical entities (which we are not saying are necessarily 'intrinsically classical', but that they certainly behave classically if only certain 'ways of interacting with them' are considered). Multiplex realism also considers that, in more recent times, we became aware of the existence of quantum and relativistic entities, whose reality could only be put in a *partial correspondence* with the properties and behaviors of the previously known Euclidean entities, i.e., that only *partial morphisms* could be found, and not perfect *isomorphisms*. Finally, multiplex realism emphasizes that if we want to deeply understand the more recently discovered non-Euclidian quantum and relativistic elements of reality, we need to become more aware of the historical 'construction aspect' of our Euclidean theater, and how it can affect our general understanding and conception of reality.

On the other hand, multiplex realism doesn't state that reality is necessarily multiple: realism can in principle be multiplex even if reality is fundamentally *singleplex*, in the sense that multiplex realism is an approach to reality that considers that certain incompatibilities, such as between relativity and quantum theories, can be more fruitfully studied if one considers the fact that their elements of reality are also, in part, the result of a constructive process. As a simple example, think of the Ptolemaic and Copernican worldviews, which consider different elements in their description of the *Solar system*, for instance as regards the Earth-Sun relative movement, depicted as the Sun moving on a circular (oblique) *ecliptic* inside the celestial sphere in the Ptolemaic description, and as the Earth moving on an elliptic orbit around the fixed Sun in the Copernican description. These different elements, however, are isomorphically linked, and thus can be understood as describing a same single reality: that of the Solar system. But as we will see, it is not clear anymore if 'multiplex realism' can be reduced, even in principle, to 'singleplex realism', when *aspects of creation* are involved in our observational processes, as appears to be the case when we consider the connection between the classical and quantum theaters.

6 The spin example

In our previous discussion, we have considered the notion of spatial separation and suggested that it was used, in our remote past, as a way to represent conditions of experimental separation, and that different 'degrees of separation' can be described by considering varying spatial distances between the objects (although we don't want to imply that this was the only motivation to introduce spatial distances). Of course, to describe all possible relations between the different macroscopic entities, additional spatial notions were also introduced, in particular the notion of *spatial direction*. However, in the same way that the classical notion of *spatial distance* has proven to be insufficient in accounting for all possible 'conditions of separation' between physical entities, we can ask if the notion of *direction* within a three-dimensional space would be insufficient to represent all possible *relative orientations* between physical entities.

Let us consider the paradigmatic example of the *spin* of a quantum entity, say of an atom, or of a molecule. When initially discovered, spin was understood as an intrinsic angular momentum carried by the microscopic entities. However, it was soon realized that it wasn't possible to associate it with a specific rotation in space. For instance, because if one tries to describe it in this way, one has to consider a superluminal velocity along the microscopic entity's periphery (when understood as a classical particle), in violation of the relativistic limit. Also, a spin, in general, cannot be represented as a *three-dimensional vector*, pointing in some direction, as is the case for the *angular momentum* of a macroscopic object. This is because in quantum mechanics a spin (and more generally an angular momentum) is described by an *operator* (defining a so-called *observable*), which cannot be simply drawn as a three-dimensional vector quantity whose components would be real numbers.

Can we however represent spin states as vector quantities, with real components? In other terms, can we construct a quantum theater in which the spin states of a quantum entity can still be regarded as directions in that space? By constructing a very general mathematical representation, called the *extended Bloch representation* (Aerts & Sassoli de Bianchi, 2014), this can indeed be done. For instance, if the spin in question is of magnitude s (according to quantum mechanics, s can only take integer or half-integer values), then the 'space of directions' that one needs to consider will have to possess $4s(s+1)$ dimensions. Thus, apart the situation of a so-called 'spin one-half entity' ($s=1/2$), which can still be described in a three-dimensional space, we see that the (Blochean) quantum theater, even when used to describe the orientation of a simple spin entity, will generally and necessarily be a space with more than three dimensions. But then, what is the relation between the directions available in the quantum theater, specifying the different possible spin states, and those available in our ordinary physical space? To answer this question, one has to start by observing that two different typologies of spin states need to be distinguished: the so-called *eigenstates* and *superposition states*. Eigenstates are by definition those states such that a space direction exists such that, if the value of the spin is measured along that direction (by means of a suitable apparatus, like a Stern-Gerlach one), the result of the measurement is certain in advance. According to EPR's reality's criterion, we can then say that eigenstates are associated with elements of reality that can be tested as from our Euclidean theater. On the other hand, superposition states are such that, whatever spatial direction is chosen for the measurement, the outcome can only be predicted in probabilistic terms, i.e., never with certainty.[3]

The difficulty in clarifying the origin of the quantum probabilities, associated with the measurement of superposition states, is generally referred to as the *measurement problem* (more will be said about it in the following). What is important here to observe is that superposition states describe conditions of the spin entity that are very different from anything related to a rotation along a spatial axis.

[3] Strictly speaking, a 'superposition state' is always relative to a given measurement. Indeed, a superposition state for a measurement can be an eigenstate for another measurement. For the purpose of our discussion, we are here using the term 'superposition state' in a more stringent way, to designate those states that can *never* be eigenstates, of whatever spin measurement (states of this kind only exist for entities whose spin is greater than one-half).

Thus, one would expect them to be genuine new elements of reality, only present in the quantum theater and totally absent from the classical one. But one would also expect the eigenstates to be, instead, those states that are still associable with specific spatial directions. This is in part certainly true, as is clear that a spin eigenstate, by definition, is always relative to a given spatial direction. However, it is not true in a general sense, as no spin states, be them superposition states or eigenstates, ever really points towards a spatial direction, within the quantum theater.

Let us try to explain the content of this last statement. If we interpret a spin as a classical 'state of rotation', then, it can be represented in our Euclidean theater by a vector of a given length, pointing toward a given direction. The length of the vector describes the value of the angular momentum (proportional to the value of the angular velocity times the moment of inertia) and the direction of the vector describes the axis of rotation. Thus, in our Euclidean theater, each 'state of rotation' is in a correspondence with a spatial direction. The situation is however different in the quantum (Blochean) theater. Indeed, it is possible to identify, within the higher-dimensional quantum theater, the subspace representing the ordinary spatial directions, i.e., those directions that are in a one-to-one correspondence with the three-dimensional Euclidean vectors, like those specifying the possible spatial orientations of the measuring apparatus. When this is done, one then discovers that none of the vectors describing the spin states in the quantum theater is ever aligned along a spatial direction, not even the eigenstates (Aerts & Sassoli de Bianchi, 2016a).

In other terms, we can say that spin entities are generally completely 'outside of space', in the sense that they are always pointing towards non-spatial directions. Thus, the spin of quantum entities provides further evidence in favor of our view of multiplex realism, i.e., that we need more than a single theater (space) to fully represent our reality. Note that this breakdown of the spatial description, in relation to spin entities, does not appear immediately for the special case of spin one-half entities, as for them the quantum Blochean theater is also three-dimensional; but as soon as two spin one-half entities are combined, one obtains a composite systems whose states already inhabit in a 15-dimensional space.[4] Now, when classical entities are combined, their angular momentum is just the sum of the angular momentum of each classical entity, from which it follows that the angular momentum of a composite system is still described by a three-dimensional vector. *But no sum of two three-dimensional vectors will ever be able to account for the emergence of a 15-dimensional vector space*. In other terms, there cannot be any simple relation between the spin-like elements of reality described in the classical three-dimensional theater and those belonging to the quantum one.

7 The ineffectiveness of Plato-Abbott's allegories

The spin example allows us to mention another important aspect of multiplex realism: the nature of the relation between the classical and quantum representations. One could naively be tempted to believe that the main difference between the quantum and classical theaters is their dimension, in the sense that the description of classical entities would simply be retrieved by means of some kind of projection from the higher-dimensional quantum theater to the lower-dimensional classical one. This would be like the situation described by the Greek philosopher *Plato*, in his famous *allegory of the cave*, where the entities he considered to have a deeper reality would cast some kind of *shadow* onto the lower-dimensional "walls" of our humanly constructed representation. A similar allegory was also conveyed by *Abbott*, in his

[4] In quantum mechanics, the combination of entities is obtained via a mathematical procedure called *tensor product*. If the complex Hilbert (state) space of an entity A is of dimension N, and the Hilbert space of another entity B is of dimension M, then the Hilbert space of the entity obtained from their combination (via the tensor product) is of dimension N times M. If the two entities are spin one-half entities, then $N = M = 2$. Also, in the *extended Bloch representation of quantum mechanics*, the dimension of the (real) state space associated with an entity whose (complex) Hilbert space is of dimension N, is of dimension $N^2 - 1$. Thus, the Blochean state space of a spin one-half entity is of dimension $2^2 - 1 = 3$, and the Blochean state space of two spin one-half entities is of dimension $4^2 - 1 = 15$ (Aerts & Sassoli de Bianchi, 2014, 2016a).

famous 'Romance in Many Dimensions' (Abbott, 1884).

Our view of multiplex realism, like the views expressed by Plato and Abbott, affirms that our Euclidean theater, similarly to Plato's cave and Abbott's Flatland, is the expression of a limited perspective. But there is an important difference: according to multiplex realism we don't have a situation where an ultimate, more encompassing representation would necessarily exist. Instead, different "caves" are more likely to exist, or to be constructible, each one offering a different and unique vantage point on our reality. In that sense, multiplex realism is more similar to *Heisenberg's pluralistic view on realism*, expressed in his *closed theories* account (Bokulich, 2008). According to *Heisenberg*, quantum mechanics was not to be considered a more fundamental theory than classical mechanics (or other theories, like statistical thermodynamics or *Maxwell*'s electromagnetism together with optics and special relativity), in the sense that for him both theories were necessary to obtain a more complete description of reality, not only because each of them would have its specific domain of validity, but also because they would correspond to final and perfect descriptions of their domains. This is in part in agreement with our multiplex view, where we have assumed that different theaters of reality can be constructed to capture the properties and relations of certain 'domains of entities', and that once a specific representation is considered, it defines a 'relational space' which remains closed (in the sense that only certain physical relations can be described into it, and not others), similarly to how Heisenberg considered certain theories to be also closed.

However, in contrast to Heisenberg, in our approach, we link the multiplex appearance of our reality to the very particular (parochial) condition in which we humans find ourselves, for historical reasons, and more specifically to the fact that we penetrate reality: (1) from within a niche which is very particular, in the sense of only containing a particular type of entities and elements of reality; (2) by means of a very particular exploratory modality, because of the characteristics of our bodies, human minds, etc. This means that we do not a priori make any claim about the nature of reality in itself. Our only claim is about 'realism', i.e., the fact that if one starts to carefully and consciously collect different elements of reality, using all means available, then because of the limitations brought about by the two above aspects, the state of affairs that will generally result is that of 'multiplex realism', even if reality itself would be unique and well defined. Considering that realistic theories will inevitably result in a multiplex view, the possibility that reality itself might be multiplex remains a possibility.

Having said this, let us stress once more that there is not only the issue of being able to find only partial, instead of full, correspondences (isomorphisms). There is also the more important matter that we cannot generally expect that, when elements of reality belonging to a given representation (like the quantum one) are viewed from our classical representation, which includes our macroscopic measuring instruments, the viewing process would always be amenable to a mere *discovery process*. This, as we know, is not the case when dealing with so-called superposition states, for which the process of measurement is not a mere observation of pre-existing properties, but of creations of properties that were non-existent prior to the measurement. In other terms, when different theaters, or caves, are put in relation with one another, there is an additional difficulty to take into consideration, which was not envisaged by Plato or Abbott in their thought-provoking allegories: when an entity that is not contained in our Euclidean theater is observed from the perspective of the latter, we do not just *discover* the lower-dimensional shadow of that higher-dimensional entity. Indeed, if the entity is in a superposition state (with respect to the measurement in question), then the outcome of the observation will not be just something to be *discovered*: an irreducible *creation* aspect will also be involved, in the sense that the value of the observed (i.e., measured) physical quantity will not be given in advance, but will be literally created by the very process of observation.

This *non-deterministic* process of creation of an outcome, resulting from the observation of 'ordinary elements of reality' on 'non-ordinary entities', like quantum entities, can be explained as a process of *weighted symmetry breaking* (Aerts & Sassoli de Bianchi, 2016b). This explanation is supported by the previously mentioned extended Bloch representation, which allows for the association of a predetermined number of non-spatial *hidden-measurement interactions,* responsible for the actualization of the available outcomes, to each measurement. The relative number of interactions associated with an outcome then determines its probability (according to the quantum mechanical *Born rule*), and since nothing in the process favors one interaction with respect to another, it is impossible for the experimenter to *a priori* determine which one will be ultimately selected (following the inevitable fluctuations that are part of a quantum measurement context and that by no means can be controlled by the experimenter without dramatically altering the measurement itself), hence the irreducible indeterministic character of a quantum measurement; see for instance (Sassoli de Bianchi, 2015), in this journal, for a simple description of the hidden measurement interpretation of quantum mechanics.

What is important to emphasize is that those aspects that are not representable in the Euclidean theater (and, more generally, described by a classical theory) correspond to what we usually describe, from the perspective of the latter, as *potential elements of reality*, or *potential properties*, and a quantum measurement is nothing but a process where *the actual breaks the symmetry of the potential*. So, when considering the interplay between the different theaters, we have to consider that the encounter between entities belonging to different theaters (for instance an electron belonging to the quantum theater and a Stern-Gerlach apparatus belonging to the classical theater) will necessarily involve aspects of creation, as a measurement process will always *force* the measured entity to acquires those elements of reality (not previously possessed) which will allow it to *momentarily enter the stage in which the measurement is performed*. This "coming on stage," however, can only occur in a perfectly indeterministic way. In fact, and this is a subtle point to grasp, it is precisely because the process is genuinely indeterministic that we can actually speak of a process of creation, i.e., that we cannot associate in advance the property that is observed before it is observed. Indeed, if the process were deterministic, the outcome would be certain, and according to the EPR criterion it would be associable with an element of reality existing prior to the measurement.

8 Reinterpreting quantum experiments

As the examples of 'entanglement' and 'spin directions' clearly show, a quantum entity, be it single or composite, cannot in general be understood as an entity belonging to our three-dimensional spatial theater, nor as a higher-dimensional classical-like entity that would simply 'cast a three-dimensional shadow' onto it. In spite of that, quantum entities can certainly maintain a stable relation with the classical entities. In other terms, it is precisely because there is a correspondence, however partial, between the elements of reality that are present in the quantum (non-spatial) theater and those in the classical (spatial) theater that we have been able to discover all the strange properties of the former. But this needs not to be the case for all existing physical entities. To remain within the example of spins, the reason why we can measure them with instruments belonging to our Euclidean theater is because, although 'out of space', they nevertheless are always in a specific relation to space and its classical elements of reality. But, there are quantum properties, for instance the *color charge* of individual quarks, which, as far as we know, and contrary to spin values, have no evident relation to space, and this may in part explain why certain entities appear to remain confined within the "quantum cave." In that respect, our analysis puts forward a possible new way to explain why color charged elementary entities, such as quarks, cannot be singularly observed, which is different from the standard more phenomenological explanation.

Once the notion of non-spatiality becomes an integral part of our description of quantum entities, much of our difficulty in understanding their nature and behavior disappears. Of course, their behavior remains strange according to our standards, as is clear that they remain non-ordinary entities, i.e., entities that were not considered when we constructed our initial representation of reality, which is the representation we also considered when, in more recent (scientific) times, we formalized our knowledge in so-called classical (Newtonian) mechanics. We have mentioned already that the senses of sight and touch have played in this a primary role. Before continuing, let us briefly explain the reasons to believe that these two senses are precisely those that have mostly fooled us into the illusion that all physical entities would be objects (things) inside space (or even that, what we call objects, can only behave as such).

Our sight, however sophisticated, is a very classical instrument, and it is probably not a coincidence that it was reinvented in our human technology as *photography camera*. It makes use of what is called in physics the *geometrical theory of light*, where the latter is considered to be formed by infinitely thin rays always traveling in straight lines. This, however, is a highly simplified theory, which is a good approximation only at the very specific scale and frequencies our eyes operate. For instance, insects have a very different type of eye, and at their scale this geometrical approximation already fails, mainly due to *diffraction phenomena*, which become dominant if a *camera obscura* type of eye becomes as small as an insect eye, causing the vision to become completely blurred. So, by using our eyes, we explore a world that is quite illusory, in the sense that we can only properly capture a portion of it: that which is compatible with our specific scale and size.

Regarding touch, we tend to believe that it provides us with a very intimate, and hence, also very deep contact with reality. But, is it really so? In principle, touch is a possibility that is mainly a consequence of *Pauli's exclusion principle*, stating that *fermions* (the "particles" of matter, also forming our body) cannot collectively occupy the same states. Consequently, if we touch a chair with our fingers, since the electrons in the fingers cannot occupy the same state as the electrons in the chair, we 'feel' an emergent pressure (called *degeneracy pressure*), expressing the impossibility not only to penetrate the matter of the chair with the matter of our fingers, but also to compress the matter of the chair into smaller volumes of space. Now, touch is a sense that certainly works on a deeper level than sight, but is also governed by a simple principle that only applies to one typology of the known physical entities: *fermions*. For example, photons, the constituents of light, which are not fermions but *bosons*, can easily occupy all the same state, independently of their number. In fact, the more of them that are in a given state, the more probable it is that others will enter that same state, an aptitude that is exploited in our *laser technology*.

Now, although they work on very different physical principles, the two senses of sight and touch are perfectly compatible with one another, as is clear that we see the chair with our eyes exactly where we perceive it when we touch it, and this "synesthesia" (understood here as a "working together, in a compatible way") has clearly contributed enormously to the illusion of a three-dimensional world formed by macroscopic objects, and to the increasingly dominant role played by our sight and touch in deciding the nature of the world we live in, despite the fact that our other senses, and the more recent "interaction" guided by language and meaning, is in principle able to bring us closer to the deeper, non-spatial layer of our reality, which we discovered in our quantum laboratories.

Quantum experiments certainly ask us to abandon the illusion of a reality that would be fully contained in space. Entangled states, as we explained already, are the expression of connections extending beyond space, and spins cannot generally be depicted as rotations along any spatial axis. But let us give another example of paradigmatic experiments that remain totally unintelligible if one tries to interpret them using the "space contains reality" prejudice: *Wheeler's delayed choice experiments*. In experiments of this kind, which were first imagined by Wheeler (1978), a quantum entity enters a measuring apparatus like, say, the one used in a *double-slit experiment*, whose arrangement, however, can be changed at the last moment, before the entity (a photon, an electron, a neutron, etc.) is finally detected. Only two possible arrangements are considered: the first one, let us call it the 'wave arrangement', corresponds to the usual one adopted in a double slit experiment, producing the typical interference effects on the detection screen; in the second arrangement, let us call it the 'particle arrangement', the screen is removed and replaced by a pair of detectors, positioned in such a way that the statistics of their clicks now becomes fully compatible with a particle description (no more interference effects); see Figure 2.

The idea of a delayed choice experiment is to change the arrangement very rapidly, but only after the quantum entity has already passed through the two slits. Many authors have successfully performed these experiments, over the last decades, exploiting different techniques and properties of the quantum entities (like the possibility to correlate the path taken by a photon with its polarization). The results are always that, even though the change in arrangement happens at the very last moment, the entity behaves compatibly with it, i.e., as if the final arrangement was there since the very beginning.

The intention behind experiments of this kind is to have the quantum entity first pass through the double-slit region, either in the particle or wave arrangements, so that, according to what we may call the *wave-particle prejudice*, it will be "forced" to either behave as a particle or as a wave. Then, just before being detected, the arrangement is suddenly changed; more precisely, if the entity entered the double-slit region in the 'particle arrangement', thus, according to the prejudice, as a particle, the screen is abruptly placed in front of the pair of detectors (see Figure 2), and if the entity entered the double-slit region in the 'wave arrangement', thus, according to the prejudice, as a wave, the screen is suddenly removed, so that the pair of detectors is operational.

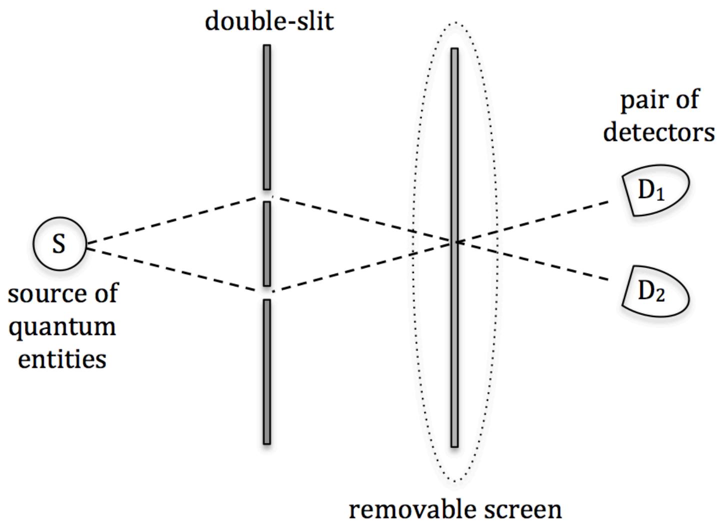

Figure 2 A schematic illustration of a delayed choice experiment. The screen is removable, and it may be either left in place (to create a 'wave context') or removed (to create a 'particle context').

Now, if we assume that the quantum entity can only be a wave or a particle, depending on the context (i.e., on the arrangement), then, once it has passed through the double-slit structure as a wave, interferences will have to take place, and it is reasonable to think that a subsequent change of the arrangement cannot make them disappear. Similarly, once it has passed through the double-slit structure as a particle, there should not be any interference effects, and again it is reasonable to consider that a subsequent change of the arrangement cannot retroactively create the interferences. But this is not what is observed when the experiments are carried out: everything always happens as if the quantum entity would have "delayed its choice" of manifesting either as a particle or as a wave, until the final arrangement of the detection apparatus is selected.

The wave-particle prejudice is already difficult to understand *per se*. How a quantum entity can transform into a particle, or a wave, depending on the context, is increasingly challenging to elucidate. But, even if this would be possible, to understand then the result of the experiments, one should also assume that the quantum entity would be equipped with some sort of precognitive abilities, knowing in advance what the final arrangement would be, and transforming accordingly either as a particle or as a wave. Or, if not capable of making predictions of the future, it should then be able to produce some kind of retro-causation. Another possibility is to adopt a radical antirealist stance, like the one of Wheeler who, facing the implications of his delayed-choice experiments, famously concluded that "no phenomenon is a phenomenon until it is an observed phenomenon,"[5] so that reality "out there" would not exist independent of our acts of observation.

But, instead of renouncing the existence of reality until it is measured, in total disagreement with the general EPR reality criterion, it is sufficient to consider that the quantum entity subjected to the experiment is neither a particle nor a wave, and in fact it is never one or the other, as particles and waves are spatial entities (particles are localized spatial entities and waves are spread out spatial entities) whereas a quantum entity, like a photon or an electron, generally behaves as a non-spatial entity. And, since the quantum entity retains its non-spatial condition for as long as it is not "sucked into space," it doesn't have to sense the apparatus in advance, nor to retroact, but just behave according to its non-spatial nature, until it is suddenly brought into space at the moment of the detection, by either interacting with the screen or with the pair of detectors. So, the quantum entity does not delay its choice of manifesting either a particle nature or a wave nature until it is detected, but is simply detected (in the present case, absorbed) in a way that depends on the *final measuring context*. The quantum entity perfectly exists prior to the detection, although it does so as a non-spatial entity, not having any specific spatial attributes, and when it is detected it manifests in a way that we can, retrospectively, interpret (following our wave-particle prejudice) as 'the effect of a particle' or 'the effect of

[5] Quoted in (Scully & Scully, 2007), p. 191.

a wave', depending on the final context.[6]

To explain this unusual behavior of a quantum entity only apparently delaying its choice of manifesting in a way instead of another, let us consider a metaphor that, as we will explain later, may be more than just that. We replace the quantum entity by a human concept and, to be more specific, by the concept 'Mouse' [this is an adaptation of an example taken from Buonomano (2011)]. The (apparent) passage of the quantum entity through the double slit apparatus is replaced in our metaphor by the concept 'Mouse' being combined with the concept 'On the table', producing the combined concept 'The mouse on the table'. On the other hand, the 'particle arrangement' and 'wave arrangement' that, according to the experimental protocol, are applied in a definitive manner only at the very end, are described in our conceptual analogy by the concepts 'Is broken' and 'Is squeaking', respectively. So, in the first case, we obtain the final combination 'The mouse on the table is broken', and in the second case the combination 'The mouse on the table is squeaking'. Finally, consider a human mind that is asked to further specify (concretize) either the concept 'The mouse on the table is broken', or 'The mouse on the table is squeaking', by picking one of the following two options: $\psi^A =$ 'The small rodent on the table is squeaking', or $\psi^B =$ 'The computer pointing device on the table is broken'. These two possible answers, in our example, correspond to a final concretization/spatialization of the abstract/non-spatial concept 'Mouse', and in our metaphor are meant to represent the two situations 'the impact on the screen is produced by a wave-like entity' and 'the click in the detector is produced by a particle-like entity', respectively.

The concept 'Mouse', in the beginning, is not embedded in any semantic context, so that its state can just be said to correspond to the "ground" state $\psi_0 =$ 'The mouse is a mouse'. Then, the context changes, and 'Mouse' gets combined with the concept 'On the table'.

[6] Consider however that microscopic quantum entities are always individually detected as localized impacts, and that it is only when an entire statistics of impacts is analyzed that a wave-like or particle-like behavior can possibly be inferred. Also, this remains true only in the description of individual entities: when systems formed by more than one entity are considered, the wave-like patterns one can possibly observe can no longer be understood as resulting from the interference of three-dimensional waves.

One can describe this situation by saying that the concept state has evolved from the "ground" state ψ_0 to the "excited" state $\psi_1 =$ 'The mouse on the table' (i.e., the state obtained by putting the 'Mouse' concept in the context of the 'On the table' concept). Then, depending on the final choice of the "arrangement" by the experimenter, this ψ_1 state is either further evolved into the state $\psi_2^A =$ 'The mouse on the table is squeaking' or the state $\psi_2^B =$ 'The mouse on the table is broken'. At this point, a human mind will interact with one of these two states to "collapse" it, by choosing one of the two more specific descriptions ψ^A or ψ^B (outcome states).

Here we are in a situation where, with a probability very close to 1, a human mind will collapse state ψ_2^A to ψ^A (in the quantum jargon, one says that ψ_2^A is very close to the eigenstate ψ^A), and state ψ_2^B to ψ^B, but less deterministic contexts could also be considered. Let us now explain why this 'conceptual metaphor' can be helpful in elucidating what goes on behind the spatial scenes in a delayed choice experiment. We have to consider that a human mind selecting the final state (either ψ^A or ψ^B) has here the scope of attributing a final (more concrete) meaning to the concept 'Mouse', when the concept is presented to it in state ψ_2^A or ψ_2^B. However, we see that this meaning remains undetermined when the 'Mouse' concept is in state $\psi_1 =$ 'The mouse on the table', and that it is only when the final conceptual fragment is added (the equivalent of the final choice of an arrangement in the delayed-choice experiment), producing either state ψ_2^A or state ψ_2^B, that this meaning can become more evident.

In other terms, a more explicit meaning of 'Mouse' is only obtained when one of the two final contexts 'Is broken' and 'Is squeaking' is added. Before that, 'Mouse' remains, within the human conceptual reality, in a more abstract state, expressing a variety of potential more concrete meanings. But even more interesting is to consider what happens in time when the mind hears, say, the sentence 'The mouse on the table is broken'. Until the last word is heard, the mind will wait to attribute a final more concrete meaning to 'Mouse', and more importantly, this more concrete meaning will manifest suddenly, as a whole. In other words, although it is certainly correct to say that the mind *delays its choice*, regarding what would be a specific meaning for 'Mouse', once this choice is made it doesn't edit retroactively the entire sequence, with 'Mouse' now replaced by 'Computer pointing device'.

So, the 'Mouse' conceptual entity subjected to the cognitive experiment is neither a small rodent nor a computer pointer device, at least for as long it is not "sucked into a more concrete conceptual space," by interacting with a specific measurement context. And it would be meaningless to say that the 'Mouse' conceptual entity would be able to sense such specific context in advance, or retroact in some way: it simply has to behave according to its abstract nature, until it is suddenly concretized, by either interacting with the 'Is broken' context or the 'Is squeaking' context. The conceptual entity 'Mouse' does not delay its choice of manifesting either as a small rodent or as a computer pointer device: it simply exists as an abstract entity, having a number of potential meanings, until it is ultimately detected by a mind-like entity, sensitive to these potential meanings, which then selects one of them in a more or less deterministic way.

9 The conceptuality interpretation

Considering the previous metaphor, one may wonder if there would be something deeper in the analogy between quantum entities and human concepts. In other terms, one may wonder if (1) human concepts would behave similarly to quantum entities, i.e., if they have a quantum-like nature, and, *vice versa*, if (2) quantum entities would behave similarly to human concepts, i.e., if they have a conceptual-like nature. In our view, both points can be answered affirmatively: point (1) resulted (for about fifteen years now) in the emerging field of investigation known as *quantum cognition*; see for instance: Busemeyer & Bruza (2012), Haven & Khrennikov (2013), Wendt (2015), Aerts et al. (2013, 2016), Aerts & Sassoli de Bianchi (2017); point (2) resulted in a novel interpretation of quantum mechanics, known as the *conceptuality interpretation* (Aerts, 2009, 2010a,b, 2011).

Quantum cognition should not be confused with the theory of the quantum brain, speculating that quantum mechanical phenomena, at the micro level, may also play an important role in the brain's function, particularly in relation to the manifestation of the consciousness. It is about applying the conceptual and mathematical formalism of quantum theory to model different cognitive situations, for instance those involving decision-making, conceptual reasoning, human memory, and other cognitive phenomena. The reason for doing so is that, in the same way physicists were confronted with data that appeared to be inconsistent when viewed from the perspective of classical mechanics and classical probability theory bringing them to the development of quantum mechanics, psychologists and cognitive scientists were also confronted with anomalous (irrational) human behavior, if analyzed according to classical logic and classical probability theory. When these behaviors where organized in the ambit of statistical studies, conducted on significant samples of subjects, the only way to explain the structure of the obtained experimental probabilities was to resort to non-classical (non-Kolmogorovian) probability models, like the Hilbert model of quantum mechanics, or even more general (quantum-like) models, neither classical nor quantum, but somehow in-between.

In other terms, assuming that human thought and reasoning is formed of two layers, a *logical* one, of an *analytical* nature (usually and erroneously taken for granted), and a *conceptual* one, of a *synthetic* nature (usually and erroneously considered to be anomalous), the first layer can be efficaciously modeled by classical probability models, whereas the second layer can only be modeled by quantum (or more generally quantum-like) probability models. Thus, depending on the cognitive situations, our minds can function either as classical or quantum machines (and many times also both, simultaneously), thus requiring not only classical but also quantum notions to be properly modeled (Aerts & D'Hooghe, 2009).

It is certainly not our intention in this article to explain, even in broad terms, the different aspects of the particular field of research of 'quantum cognition' and the successes that have marked its rapid expansion over the last years (in particular, how it was possible to describe the highly *contextual* and *indeterministic* part of human cognitive processes by exploiting the quantum formalism and some of the most salient features of quantum systems, like *superposition*, *interferences*, *correlations due to entanglement* and even the 'many-body effects' typical of *quantum field theory)*. Let us however mention that different approaches exist, adopting different ontologies, and that the approach that was taken by the Brussels' group, since the dawn of this new field of study, was an *operational-realistic* one, where the different conceptual entities interacting with the human minds are considered to possess objective (i.e., intersubjective) properties, independent from the minds possibly interacting with them (Aerts et al., 2016).

More precisely, according to Brussels' operational-realistic approach to cognition, human concepts can be viewed as 'meaning entities' that can be in different states, depending on the context in which they are, as we suggested already in our previous 'Mouse' example. Concepts can combine, forming 'composite conceptual entities', and when they do so they can 'connect through meaning'. These meaning connections can create correlations (of the second kind), which in turn are able to violate Bell's inequalities, exactly in the same way quantum correlations can do. In other terms, entanglement systematically occurs in human cognition in a way that is similar to quantum entanglement (Aerts et al, 2000, 2011, 2018a,b).

Similarly, the states of human concepts can 'collapse' as the states of quantum entities do, transitioning from more *abstract* superposition states to more *concrete* eigenstates, during the measurement (interrogative) processes. If, in a 'physics laboratory', the collapse is produced by the interaction with a measuring apparatus, in a 'psychological laboratory' the collapse is produced by the interaction with a human mind, playing exactly the role of the measuring entity, when selecting one among the available outcomes, taking into consideration, for instance, their *representativeness*, or *typicality*. But as soon as one acknowledges the quite amazing analogies between human concepts and quantum entities, and between psychological measurements and quantum measurements, one is forced to also consider that the analogy works in both directions, i.e., that quantum entities may actually behave in such a strange way precisely because they would not be objects (like particles, corpuscles, bodies, waves, fields, etc.), but *conceptual entities* (although of a non-human kind) able to be in states of different degrees of abstractness, interacting with each other in a similar way as human concepts combine with each other, and interacting with the different measuring devices in a similar way as human concepts interact with the human minds.

10 The relativistic principle

We would like now to add a different example of entities that cannot be easily incorporated in our Euclidean theater: the relativistic ones. Usually, the term 'relativistic' refers to entities that would make manifest the so-called *relativistic effects*, as described in Einstein's special relativity theory, because they would move in space at speeds comparable to the speed of light. In the following, we will not consider quantum entities, in the sense that we will not assume that these *relativistic entities* would be subjected to indeterministic measurements, contextuality and emergence effects that are typical of quantum entities. We really consider them, for the moment, to be just classical bodies that can move in space.

The term 'relativity' has been historically attached to Einstein's work; however, it more exactly refers to a principle – the *principle of relativity* – which is much more ancient. It was described by *Galileo Galilei*, in his 1632 dialogue concerning the two chief world systems, with his famous example of the ship advancing at uniform speed, with people locked in the cabin beneath the deck of the ship not being able to determine (by observing different phenomena) whether the ship was moving or just standing still (Galilei, 1632). But one also finds descriptions of this principle as early as the first century B.C., that is, 1700 years before Galileo, in China. In the *Apocryphal Treatise on the Shang Shu Section of the Historical Classic: Investigation of the Mysterious Brightnesses* (*Shang Shu Wei Kao Ling Yao*), we can indeed read: "Although people don't know it, the earth is constantly moving, just as someone sitting in a large boat with the cabin window closed is unaware that the boat is moving."

In a nutshell, the relativistic principle can be enounced as follows: "Equivalent viewpoints exist on the physical world." When formalized using the more specific notion of *reference frame*, it then becomes [see for instance Lévy-Leblond (1977)]: "Equivalent frames of reference (space-time coordinate systems) exist for the physical laws, i.e., such that the physical laws have exactly the same form in all of them." This doesn't mean that the values of the different physical quantities will be the same in the different equivalent reference frames: it simply means that they will obey exact the same relations, which in turn means that phenomena will be observed exactly in the same way, when viewed from these different equivalent reference frames.

Of course, not all reference frames will be equivalent. When for instance we are on a carousel, which is rotating at a given speed, we will observe and experience phenomena that would be absent if the carousel would be at rest, such as the well-known centrifugal pseudo forces. So, the interesting content of the principle of relativity is that, among the infinite number of possible reference frames, some exist that are perfectly equivalent. Now, the simplest (and in a sense also trivial) examples of equivalent reference frames are those that are just translated, i.e., that differ from one another simply because they don't share the same origin for the spatial and temporal coordinates. Another possibility is that of reference frames whose axis would have different orientations. But Galileo, and before him the ancient Chinese sages, identified a more interesting and non-trivial class of equivalent reference frames: those *moving at a constant speed* with respect to the others, nowadays called *inertial frames*.

The fact that inertial frames are equivalent has some remarkable consequences: one is that an object moving at constant speed must be characterized, from the viewpoint of the physical laws, in exactly the same way as an object at rest, and such characterization is that of an absence of forces acting on the object. The so-called *principle of inertia* (also known as the *first law of Newton*) immediately follows: like an object at rest, an object in motion at constant speed will remain in such state of motion forever, unless acted upon by a force. But there is a more dramatic consequence of the relativity principle, which certainly hasn't been fully appreciated until Einstein's relativity came on the scene, many centuries after Galileo: if inertial frames are equivalent frames, then making sense of a notion of *absolute movement* is no longer straightforward.

This means that, already considering the Galilean principle of relativity, and long before the advent of Einstein's theories, our understanding (theorization) of space dramatically changed in comparison to our initial 'penetration in width' of the ordinary physical reality present on the crust of our planet. Indeed, if making sense of an 'absolute state of spatial movement' becomes convoluted, this has consequences for the possibility of making sense of the notion of *space as a fundamental substantive container*. In other words, the ancient Chinese sages, or Galileo, if they had given careful consideration to all consequences of their boat examples, they could have come to the conclusion that 'a notion of space, as a theater for the whole of our reality, is problematic'.

The principle of relativity, with the existence of the non-trivial equivalent inertial frames, tells us that space is most probably essentially a *relational construct*. And, if we continue along such a hypothesis, since each entity has then a unique perspective, it follows that *each physical entity actually inhabits a different space*, i.e., a different relational spatial structure. This becomes an almost trivial observation if one considers the so-called *parallax effects*, i.e., the fact that the different entities, because of their different viewpoints, will generally locate a singular object in different positions. Of course, one can immediately object, and rightly so, that when we combine all these different viewpoints, a 3-dimensional structure will emerge, which is precisely the 3-dimensional Euclidean space, perfectly explaining the parallax effects. In other words, it is precisely because parallax effects exist that we can say that we all inhabit a *same* space.

This is indeed correct, and in fact it is precisely what animals (like us) with a *binocular vision* have learned to do: to develop a 'perception of depth' (not to be confused with the notion of 'penetration in depth' introduced in this article), obtained from the different viewpoints of each of their two eyes (*stereopsis*). So, spatial parallax effects are certainly not sufficient *per se* to support the idea that each entity would construct an individual relational space. In fact, the idea of the existence of an objective "container space" is further reinforced by the fact that not only can we deduce this space by combining all these different perspectives, but also that *we can see the different entities moving into it*.

However, do we see entities moving in space because they actually move in a spatial theater, or is it just because we confer to them a spatial movement to "keep them inside our personal spatial representation"? This may look like a twisted question, trying to complicate things rather than simplify them. But the question is more than legitimate, considering that the principle of relativity tells us that it is not straightforward to make sense of an 'objective state of (spatial) movement'. If we can certainly all agree on the fact that an entity is present in space in some location (which will be described by different numbers in the different reference frames), it is no longer possible to agree on the fact that such entity would be 'moving in space', as for some observers it will be perceived to be at rest. Thus, if on one hand movement is what allows us to 'keep entities in space', it is also what is telling us that there cannot be a single all-encompassing spatial container for all the existing physical entities.

The situation becomes much more dramatic with the passage from Galileo to Einstein. The so-called *Galilean transformations*, used to transform between the coordinates of different Galilean inertial frames, only concern the transformation of the spatial coordinates, not the temporal ones. In other words, if two Galilean inertial observers will generally attach different coordinates and velocities to a same object, they will nevertheless describe time (i.e., the movement of their clocks, also called, although improperly, the *time flow*[7]) in exactly the same way. With the advent of Einsteinian relativity, these transformations are replaced by the more general *Lorentz transformation*.

The difference between the Galilean transformations and the Lorentz transformations resides in two important aspects. The first one is that in the Galilean case it was taken for granted that *standards of length* had to remain the same in the different inertial frames. In other words, it was assumed that the length of objects would remain the same when measured from different inertial frames. This assumption was clearly natural at the time of Galileo, as this is what was actually observed, and logical, considering the preconception of living entirely in a three-dimensional theater. But when motions at speeds that are no longer negligible with respect to that of light were considered, a different scenario was revealed: objects, when moving, are measured to be shorter in comparison to when they are at rest.

The second aspect distinguishing the Galilean from the Lorentz

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[7] We don't have to commit the mistake of confusing something with its function. When we say that 'time flows', it is a bit like saying that a 'walkway walks'; a walkway cannot walk: a walkway is what allows people to walk. Similarly, time is what allows 'reality to flow', and therefore it cannot itself flow. So, when we improperly speak about the flow of time, what we have to understand is that we are really talking about the process of change of those special entities that we call clocks, which we use as a reference to measure the processes of change of all the other evolving entities.

transformations is even more unexpected and, in a sense, remarkable: clocks, when they move, run more slowly in comparison to clocks that are not moving. In other words, if it is true that the Galilean relativity has indicated (although this has never been really taken sufficiently seriously) that we don't live in a single three-dimensional container, as each entity "constructs" its own space, Einsteinian relativity adds to the picture the fact that these spatial theaters are not just spatial, but spatiotemporal.

11 A 4-dimensional representation

That each classical (in the sense of non-quantum) entity can be viewed as immersed in a four-dimensional spatiotemporal representation is in fact easy to demonstrate. For this, let us consider the following *gedankenexperiment* [see (Aerts, 1999), for more details]. Imagine being in Geneva, Switzerland, and that it is May 18, 2017, 3 pm. Let us call this the present moment t_0. When in Geneva, at time t_0, since you are having a direct experience with the city, you can safely affirm that Geneva is real for you, i.e., that Geneva is an existing part of your present material reality. But what about the reality of the city of Miami, at the same time t_0? Since you are not having an experience with the city of Miami, can you nevertheless affirm that it is also part of your present reality, at time t_0? The answer is affirmative, and the reason for this is that, following EPR's reality criterion, we know that *reality is a construction about the possible*: if, in your past, you would have decided to travel to Miami, then *with certainty* you would have had a direct experience with Miami at the present time t_0, and based on the certainty of such a prediction you are allowed to affirm that also Miami is an existing part of your material reality, at time t_0.

But consider now Geneva not at time t_0, but at subsequent time $t_1 > t_0$, where t_1 is, say, May 19, 2017, 3 pm,[8] that is, twenty-four hours in your future with respect to the present time t_0. Is Geneva

[8] This is the day when the *2nd International Congress on Consciousness* started in Miami, where the content of this article was presented by one of the authors.

at time t_1 part of your present material reality? The answer we would give to this question, based on our parochial (Newtonian) conception of space and time, is that this cannot be the case, as Geneva at time t_1 being in your future, it cannot be already real, i.e., part of your present material reality. But this would be a wrong conclusion considering what we know about relativistic effects and more particularly about the effect of *time dilation* (the slowdown of the ticking rate of clocks when they are moving, as compared to clocks at rest).

More precisely, if in the past, say on May 17, 2017, 3 pm, you would have decided to use your space ship to travel at a speed $v = \sqrt{3/4}\,c \approx 0.866\,c$, with c the speed of light,[9] then by performing a suitable round-trip journey to any spatial direction, and because of the effect of time dilation, you could have been back in Geneva exactly when your smartphone would indicate May 18, 2017, 3 pm, whereas the smartphones of all other Geneva's inhabitants would indicate May 19, 2017, 3 pm. Thus, if you take seriously the EPR's reality criterion, you are forced to conclude that Geneva in twenty-four hours is also part of your present material reality.

Let us explain to the reader who is less versed in relativity theory how this time dilation effect can be calculated. We have two different versions of you, one remaining always at rest with respect to the Geneva's referential frame,[10] let us call it the *A*-version of yourself (or simply the *A*-entity), and the other one who, at some moment in the past, decides to use a space ship, let us call it the *B*-version of yourself (or simply the *B*-entity). If T_B is the time-period of the clock used by *B* when traveling with the space ship, as measured by *A*, then when comparing it to the time-period T_A of an identical clock remaining in Geneva, *A* will observe an *effect of time-dilation*. More precisely, if v is the speed with which *B* moves away from *A*, or approaches *A*, then, defining the so-called *Lorentz gamma factor* $\gamma = 1/\sqrt{1 - \frac{v^2}{c^2}}$ (a number strictly greater than

[9] Assuming that such spaceship, which is not forbidden by the laws of physics, would be already available.

[10] Of course, Geneva, being part of planet Earth, cannot really be associated to an inertial frame, but for simplicity we will neglect the planet's non-uniform motion.

1, if $v > 0$, whose value in our example is precisely $\gamma = 2$), we have the relativistic time-dilation formula: $T_B = \gamma T_A$, and more specifically in our example $T_B = 2T_A$, i.e., the clock on board the ship appears to *A* to run twice as slow than the clock that remained on Earth.

Imagine now that the *B*-entity performs a return trip, always going at the same constant speed v (of course, there will be accelerations at the departure, turnaround and arrival, but let us neglect them to simplify the discussion). If we assume that the *A*-entity measures n_A cycles of his clock for the entire duration of the *B*-entity trip, then we can ask what the duration of the trip as measured by the B-entity is. In other words: how many cycles n_B does the clock of the *B*-entity perform during its trip? For this, we have to solve the equation $n_B T_B = n_A T_A$, and because of the above time-dilation formula, we can write: $n_B \gamma T_A = n_A T_A$, from which it follows that: $n_B = \gamma^{-1} n_A$, so that, for our choice of traveling speed, we have $n_B = n_A/2$. We thus find that the traveling *B*-entity uses half the time cycles of the non-traveling one.

To calculate the time t in the past with respect to the present time t_0 (corresponding to May 18, 2017, 3 pm) at which the *B*-version of you would have needed to start its trip at the speed of $v \approx 0.866\, c$, to be back in Geneva at time t_1 (corresponding to May 19, 2017, 3 pm), with the traveler's clock indicating May 18, 2017, 3 pm, we have to reason as follows: let $n_A = (t_1 - t)/T_A$ be the number of cycles performed by the *A*-clock while the *B*-entity travels, and let $n'_A = (t_1 - t_0)/T_A$ be the number of cycles corresponding to a 24-hour period. We want the number n_B of cycles performed by the *B*-clock during his trip to be exactly $n_B = n_A - n'_A$ (i.e., we want the *B*-clock to use 24 hours less than the *A*-clock) and since we have $n_B = \gamma^{-1} n_A$, we can easily solve the previous equation for n_A. This gives: $n_A = n'_A/(1 - \gamma^{-1}) = 2n'_A$. In other words, the *B*-entity has to start her travel two days before May 19, 2017, 3 pm, that is, at a time t corresponding to May 17, 2017, 3 pm (see Figure 3).

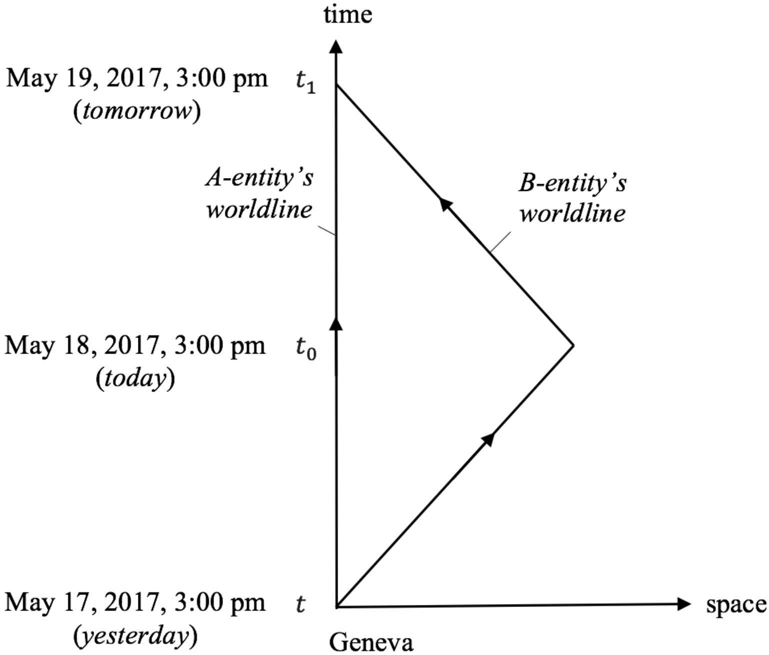

Figure 3 The two worldlines of the *A*-entity and *B*-entity, in the spacetime associated with the former. The *A*-entity remains at rest, thus only moves along her time axis, whereas the *B*-entity goes for a round-trip journey, at constant speed $\boldsymbol{v}$, which allows her to meet again with the *A*-entity, in her future.

Therefore, as we said already, considering that our reality is defined in a *counterfactual way* (by means of the EPR criterion), we are forced to accept that our present also contains part of our future, as a consequence of the existence of the *generalized spatiotemporal parallax effects* that the Einsteinian relativity has unveiled to us. Although these are just perspective effects, describing *appearances*, they are not any less real, as many experiments have clearly demonstrated. Just to give an example, a *muon* (an elementary particle similar to the electron) has a *mean lifetime* which is of the order of a *microsecond* (10^{-6} seconds), if measured in a referential frame in which it is at rest. Muons that are produced by cosmic rays in the upper atmosphere, however, can travel at speeds close to the speed of light, with respect to Earth's reference frame. If one calculates the average distance they should be able to cover, if we don't take into account the time-dilation relativistic effect, it should only be of a few hundred meters. However, because time-dilation effects are 'real appearances', they actually have (from our earthly perspective) a much longer mean lifetime, and are able to travel distances of several kilometers, in perfect accordance with the relativistic formulae.[11]

Coming back to our general discussion, if it is true that Galilean relativity has already told us that the physical entities are not immersed in a substantive objective space, but that each one "constructs" (or "sees") a personal different 3-dimensional relational space, Einsteinian relativity pushes this even further, telling us that entities are not immersed in a substantive objective space and time, but that each one "constructs" a personal and different 4-dimensional spacetime. This means that time is now viewed in a way that becomes much more similar (although not equivalent) to space, i.e., as a way for each entity to represent how the other physical entities evolve and the possible encounters they can have with them.

What is relevant for the thesis we are presenting in this article is that if it is true that relativity points to the existence of different spatiotemporal representations associated with the viewpoints of the different evolving physical entities, this also automatically points to the existence of an underlying non-spatial and non-temporal reality. So, similarly to quantum mechanics, relativity becomes truly understandable only if one is bold enough to introduce the hypothesis that physical entities are essentially non-spatial and non-temporal. And as we are now going to explain, the view that physical entities would have primarily a conceptual nature does not only offer an explanation for the strangeness of the quantum effects, but also for the relativistic ones, which by the way are usually erroneously considered to be less surprising than the former. But before this, and for sake of clarity, a remark is in order.

When we observed that 'Geneva tomorrow' is also part of your present reality, this shouldn't be understood in the sense that the future would already be given. In every moment, our reality is shaped by continuous acts of creation. For instance, this article,

[11] This is our perspective from Earth's reference frame. From that of a reference frame associated with the muon, what will be observed instead is a (Lorentz) *length contraction*, which can equivalently explain the unusual survival over distances of the relativistic muon.

before it was written by its authors, it was not part of their present reality, despite the fact that it is now a fully created entity which is available to be part of the readers' experiences. In other words, what we are describing is not an unchanging *block universe*, where everything would be given once for all, because time would possess an ontology similar to space. In fact, our view is telling us precisely the opposite: that spacetime is just how the physical entities can represent, each one in a different way, a portion of the processes of creation and discovery in which they participate. Although in a given reference frame we can always attach a time and space coordinate to a given event, this doesn't mean that the processes of change that have given rise to it are also in space and time. In our view, they typically originate from an underlying reality that is genuinely non-spatiotemporal. But non-spatiotemporal does not mean that it would not be a *process reality*, where entities would not be able to change state, interact and evolve, in both deterministic and indeterministic ways. It is just that this non-spatiotemporal reality is a more abstract realm, which remains hidden from our parochial spatiotemporal perspective.

12 Explaining time dilation

Let us come back to our example of the two versions of you, one remaining at rest with respect to Geneva and the other one performing a return trip. If these two versions are considered to be two twins, we have the well-known situation of *Langevin's twin-paradox*, where the twin who makes the journey, when he returns home, discovers that his brother has aged more than him. The reason why it is called a paradox is not the observation of this age difference, but the fact that one could argue that if we consider the viewpoint of the reference frame associated with the space ship, then it is the twin remaining on Earth that appears to perform the return trip. However, this apparent symmetry between the two descriptions can be easily broken by observing that the two frames of reference are non-equivalent, as the frame associated with the twin traveling with the spaceship is a non-inertial one. Thus, the symmetry is broken by observing that the traveling twin experiences accelerations that are not experienced by the non-traveling one.

If the presence of accelerations allows one to eliminate the paradox, one should not conclude for this that the observed time-dilation effect (or length contraction effect, from the viewpoint of the traveling twin) would be caused by these accelerations. It is in fact not difficult to convince oneself that it is really the geometric structure of the *worldlines*[12] associated with the two brothers that is responsible for the time dilation effect, as the latter is truly defined by the (Lorentz-invariant) length (corresponding to the so-called proper time interval) of their worldlines (Aerts, 2018).

But how can we understand this very strange effect of time dilation? For this, imagine that the two twins, A and B, are not just 'bodies moving in space', but, at a much more fundamental level, 'mind-like entities having some meaning driven interactions'. Assume that they both start reflecting on a problem, at time t, on a given hypothesis about which they both agree. In other words, in the conceptual space that they both inhabit, they have a first encounter at the "place" of this commonly shared premise. Imagine then that entity A, after n_A *conceptual steps*, reaches a given conclusion, and that to keep track of her cognitive path, A decides to introduce an axis to parameterize each one of her n_A conceptual steps. By ascribing a unit to this axis, corresponding to the length L_A of a single conceptual step, then assuming that the duration of such step is T_A, and that the speed with which it is accomplished is c, we can simply write: $L_A = cT_A$. Thus, going through her reasoning, from the hypothesis to the conclusion, A performs n_A conceptual steps, each one of length L_A, thus moving on her 'order parameter axis' from point $L = ct$ to point $L_1 = ct_1 = L + n_A L_A = c(t + n_A T_A)$.

Consider now entity B. Differing from entity A, we assume that her reasoning allows her to reach the same conclusion (starting from the same hypothesis), but in a lesser number $n_B < n_A$ of conceptual steps, and let us consider for simplicity that, as in our previous example, $n_B = n_A/2$. Imagine that entity A is also willing to keep track of the cognitive path of entity B, consistently with the

[12] The worldline of an entity is the path traced in the 4-dimensional spacetime describing the history of its location in space at each instant in time.

fact that they are at the same "place" when they share the starting hypothesis, and that they can meet again at a common "place" when they reach the same conclusion. We assume that *A* and *B* are equivalent entities, in the sense that when they take a cognitive step, they always do so at the same speed *c*.

Now, since *B* is able to reach the same conclusion in half the number of steps of *A*, the latter cannot represent her path on the same axis, as units were precisely chosen on the latter in a way that one needs twice the number of steps to reach the final conclusion. So, *A* has to find a different way to represent the cognitive process of *B*, by introducing an additional axis, to describe *B* as moving on a round-trip path which will be now contained in a higher dimensional space, generated by the first parametric axis. Let us call it the 'time axis of *A*', and this second parametric axis, let us call the 'space axis of *A*'.

So, entity *B* is now described as following a conceptual path that moves away from the initial "hypothesis point," on the time axis, and then comes back to reach the "conclusion point," always located on the time axis, by doing exactly $n_A/2$ cognitive steps. However, if we consider this construction from a purely Euclidean perspective, we immediately see that there is a problem. Indeed, if we calculate the length of the *B*-path using the Pythagorean theorem, we will necessarily find a longer path than that walked by *A* (see Figure 4).

But we know that *B* follows a shorter conceptual path, as is clear that she only uses half of the conceptual steps used by *A*. Accordingly, when measuring its conceptual length, this should be shorter and not longer than that of the path followed by *A*. For *A* to fix this problem, there is only one way to go: it has to consider a *pseudo-Euclidean* space, instead of a Euclidean one, and more precisely that specific pseudo-Euclidean space known as the *Minkowski space* (or spacetime). In the latter, distances are not calculated using the usual *Pythagorean theorem*, but using a *pseudo-Pythagorean theorem* that attaches a negative sign to the squares of the components associated with the space axis, and a positive one to the square of the components associated with the time axis. In this way, the length of the hypotenuse of a right triangle, whose catheti are associated with the time and space axes, respectively, will generally be less than the length of the time-cathetus.

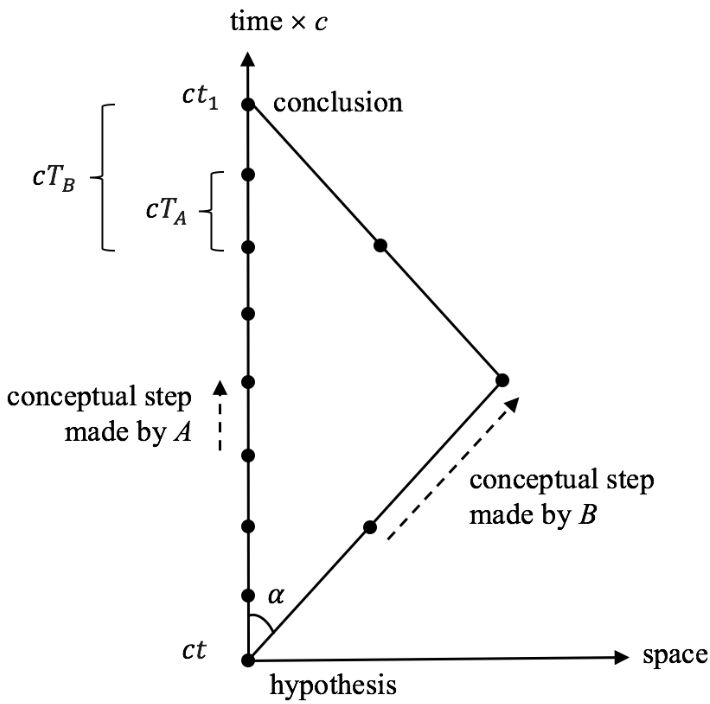

Figure 4 The coordination of the conceptual paths followed by the two entities *A* and *B*, in the spacetime constructed by the latter. When measured along the *A*-time axis (here multiplied by the light speed *c*) the length of the conceptual steps acted by *B* appear to be longer than those acted by *A*. However, when measured along the direction of its own movement in the *A*-spacetime, using the Minkowski instead of the Euclidean metric, one finds that the two entities' conceptual steps are exactly of the same length, in accordance with the fact that they would both move at the same speed *c* in the underlying conceptual reality.

Thanks to this pseudo-Pythagorean theorem, it becomes possible for the length L_B of a single conceptual step of *B* (see Figure 4) to be exactly equal to the length L_A of a single conceptual step of *A*, i.e., to have the equality $L_B = L_A$. This is a must because, as we said already, we are assuming that the two entities *A* and *B* move at the same speed *c* in their common conceptual reality, and that the duration of a single conceptual step is an *invariant*, i.e., is the same for all entities.

According to the pseudo-Pythagorean theorem, if L is the space component of the length of a conceptual step of *B*, relative to the space-axis of *A*, we have: $L_B^2 = (cT_B)^2 - L^2$. Considering that $L_B = L_A$ and $T_B = \gamma T_A$, a simple calculation shows that: $L = vT_B$. In other words, entity *A*, by adopting a pseudo-Euclidean (Minkowski) metric, is able to construct a spacetime theater in which she can keep track, in a consistent way, not only of its cognitive processes, but also of those of other entities.[13] For this, all it has to do is attach an appropriate spatial velocity v to them.

So, from the viewpoint of the underlying conceptual realm, the reason for the time-dilation effects becomes now very clear: since *A* has to parametrize the "cognitive movement" of *B*, and to do so the latter must have an angle $\pm\alpha$ with respect to the direction of the cognitive movement of *A*, with $\alpha = \tan^{-1}\frac{v}{c}$, inevitably there will be spatio-temporal parallax effects: *A*, form her viewpoint, will see *B* as if she was producing cognitive steps (cycles) having an increased duration $T_B = \gamma T_A$, that is, will see *B* as if she was reasoning more slowly than her, but since she would also reason more efficaciously (by using a lesser number of cognitive steps), they can nevertheless meet again at the conclusion point. This, however, is just how things *appears to be* at the level of the spacetime construction that is operated by *A*. At the more objective level of the non-spatiotemporal conceptual space, in which both *A* and *B* are immersed, they would both move at exactly the same speed *c*:[14] the intrinsic speed at which they both perform their conceptual steps.

13 Quantum and relativity

Our description of time-dilation effects would require more explanation to make it fully intelligible, but this we cannot do in the limited space of this article. So, we refer the motivated reader to (Aerts,

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13 When considering only two entities, one does not need more than a single space dimension to represent the second entity in the spacetime of the first one. However, additional space axes become necessary if one consider additional entities; for more details, see (Aerts, 2018).

14 In the relativistic formalism, the clue that all entities actually move at the intrinsic velocity *c* can be found in the mathematical fact that the length of the *four-velocity vectors* is always precisely equal to *c*.

2018), where more details about this construction can be found, which surely begs to be further explored and investigated to be fully understood.

Our main point here was to emphasize that relativity theory, similarly to quantum mechanics, points to the existence of a non-spatio-temporal realm, probably of a conceptual-like nature. The non-temporal aspect of this deeper conceptual reality should not be understood, however, in the sense that nothing would ever change in it. On the contrary, every physical entity would constantly surf over it, at the light speed *c*, continually producing new conceptual steps. So, movement would be incessant, and in a sense absolute, at this more fundamental level. However, time and space would be absent there, because they would only emerge when an entity coordinates aspects of her and others' movements by introducing a specific coordinate system, first by considering a time axis, to give an order to its own conceptual steps, then by introducing additional spatial axes, to put these personal steps in relation to those accomplished by the other physical entities. When this is done, as we have tried to outline in the above description of the traveling twin, one observes that movements in the conceptual reality cannot be mapped into movements happening only in space, but also in time (i.e., also along the time axis), in a way that can certainly affect how an entity can reach out into the future, explaining why not only 'Geneva now', but also 'Geneva tomorrow', can be part of one's present reality.

One may ask: If the Minkowskian construction is the one used by all physical entities (not just observers) to create a common space of encounters, then why does it remain so counterintuitive to us humans? This is because we have evolved on this planet mostly being surrounded by entities moving extremely slowly in space with respect to one another. In other words, our ordinary reality is formed by spatial entities that are almost at rest with respect to one another, so that the relativistic spatiotemporal parallax effects have remained mostly unnoticed, and therefore have not been integrated in our mental representation of the world. The same is true for the quantum effects, which mankind only discovered very recently, thanks to our accurate laboratory experiments, particularly at the microscopic level. What is fascinating is that both relativity and quantum mechanics point to the existence of a non-spatial and non-temporal (more fundamental) layer, which is the ambit that probably needs to be considered when attempting to construct a fully consistent theory of *quantum gravity*.

Now, when considering quantum entities, instead of classical ones, the duality between 'time' and 'space' needs to be replaced by a duality between 'time' and the 'set of outcome states' of a measurement. This will introduce the additional ingredient of indeterminism, as the actualization of an outcome generally involves a symmetry breaking process (Aerts & Sassoli de Bianchi, 2016b).

We have already mentioned in this article the *extended Bloch representation* (Aerts & Sassoli de Bianchi, 2014, Sassoli de Bianchi, 2015), which can be used to construct a *quantum theater* in which the measurement processes of a quantum entity, and the associated sets of outcome states, can be fully represented. In the simple example of a spin one-half entity, only admitting two-outcome measurements, the quantum theater requires only three dimensions, but for more complex entities, admitting sets of *n* possible outcomes, the number of required dimensions appears to be equal to $n^2 - 1$. Technically speaking, this corresponds to the *number of generators of the so-called SU(n) group of transformations*, which can be roughly interpreted as a group of "generalized rotations." This means that to enter the quantum (Blochean) theater, where measurements can be represented, one has to somehow "rotate away" the inherent complexity of a quantum entity, by means of these generators, in a way which will depend on its specific state.

The spin observables of a spin one-half entity, the so-called *Pauli matrices*, are in fact a particular example of these generators, for the $n = 2$ case. Thus, one can also speculate that spin is precisely an example of that very special "twist" one needs to add to a physical entity to allow it to enter a spacetime theater. As we have tried to explain, spacetime would be a creation produced by the "surfing" of the entities over a more fundamental conceptual-like reality. The latter, however, would be a much more complex and higher dimensional reality than the one representable in a global spacetime theater. This greater complexity and higher dimensionality manifests first of all in the fact that each entity must bring with it its personal spacetime construction. This however would still not be sufficient for representing also the evolution of the other entities. For this, their complexity has to be in part singled out ("rotated away"), and spin might very well be the manifestation of this "subtraction operation," allowing the quantum entities to manifest in spacetime theaters.

Let us offer a simple analogy from human cognition, to better explain what we mean by this. We can compare a spacetime theater with a well-defined 'space of discourse', like for example a given political agenda. In order to be able to fit individual words or sentences into this space of discourse, they will have to carry some specific "twists," which will make them appropriate to be part of it. These "twists" would play the same role in allowing certain terms to enter a given human space of discourse as the role played by the "spinorial twist" in allowing quantum entities to become available to enter a given spacetime theater.

14 Perspectives

Approaching the end of this essay, let us offer some more speculative perspectives, which however can be seen to be the logical consequence of what we have so far described. In that respect, let us recall that the content of the present article has been presented at the *2nd International Congress on Consciousness*, which took place in Miami, Florida (USA), from May 19 to 21, 2017. The idea behind this congress is that of promoting an open exchange and debate on research centered upon the consciousness, with particular emphasis on the importance of a *multidimensional paradigm* to explain the numerous phenomena related to the manifestation of the consciousness, like *extra-sensory perceptions* (ESP), *psychokinetic phenomena* (PK) and *extracorporeal phenomena* (OBE and NDE).

In (Sassoli de Bianchi, 2015), one of us proposed to consider, in addition to the well-known easy and hard problems of consciousness, as defined by Chalmers (1995), a *serious problem of consciousness*, which is about the identification of models and mechanisms able to explain the aforementioned *parapsychic phenomena*. The adjective "serious" is to be understood in the double sense of indicating that this is undoubtedly a difficult problem, but also a problem that requires taking seriously not only the ordinary manifestations of the consciousness, but also the (apparently) extra-ordinary ones.

There are many reasons why the 'serious problem of consciousness' is currently not openly addressed in academia, but it is not our intention to enter into this delicate and highly polarized debate. Let us mention however what is probably the most commonly evoked one, which is summed up in *Carl Sagan*'s famous quote, saying that: "extraordinary claims require extraordinary evidence." One should however ask: What determines the extraordinariness of a claim? Undoubtedly, this depends on how easily it can be integrated in the *dominant worldview*, that is, in the commonly adopted conceptual map that is used to construct a global image of the world and of the aspects that we think we can experiment with.

If we adopt the (false) *parochial worldview* of a reality fully contained in a three-dimensional substantive space, then surely claims about the reality of, say, *telepathic and precognitive phenomena*, will be evaluated being as extraordinary as claims about the reality of flying unicorns. However, if we adopt a less parochial view, like the one of multiplex realism that we have presented and motivated in this article, then phenomena like telepathy and precognition can be considered to be rather ordinary, and in fact the extraordinary claims requiring extraordinary evidence would become those affirming that parapsychic phenomena could not be real.

In a sense, we can say that if parapsychic phenomena are generally evaluated as unreasonable phenomena by the majority of modern scientists, it is because, notwithstanding the quantum and relativistic revolutions, they are still maintaining an antiquated 'Newtonian-like worldview'. However, if we take quantum physics seriously, then we must accept that our physical reality is fundamentally non-spatial, and if we take relativity seriously, we also have to accept that reality is fundamentally non-temporal; and if we reflect attentively about the behavior of quantum and relativistic entities, we must surrender to the fact that it is much more similar to that of concepts than that of objects.

But then, if it is true that reality, at a deeper level, is non-spatiotemporal, each time the state of a physical entity collapses into a localized spatiotemporal state, the process will necessarily produce correlations both over space and over time, as is clear that a non-spatiotemporal state (a non-local state both in space and time) will generally describe a superposition over different spacetime regions.

Consider for instance precognition, i.e., the possibility of "seeing" future events. There is of course a "down-to-earth" way to know about future events, which is that of using knowledge about the initial condition of a system and the laws governing its evolution. If these laws are deterministic, future events can be seen, in principle, with arbitrary accuracy, whereas if they are indeterministic, as in quantum measurements, then the future will only be available (predictable) in probabilistic terms. As an example, consider a cat sitting on your sofa. If you caress it, you could predict with great confidence that soon it would start purring. This is a prediction based on the description of a process happening in the ordinary spatial theater, i.e., at the level of our "ordinary macroscopic material reality." However, we should not forget that without a human mind producing an abstraction it would be impossible to make a prediction in the first place; so, even for such a "down-to-earth" way of understanding precognition, when everything is already collapsed into the ordinary material space, it would be wrong to consider that a more abstract cognitive-like realm would not also be involved in the process.

We can call this more abstract reality, needed to produce ordinary predictions, the "down-to-earth-mind." The time-like causal connection that the "down-to-earth-mind" is able to reveal is not however one that can produce genuine precognitive phenomena, as usually understood. Indeed, our "down-to-earth-mind" (that part of our human mind that we use in our everyday intraphysical life, to move around, take ordinary decision, etc.) can only penetrate very coarsely and in a very limited way into the more abstract 'meaning realm' of our physical reality. However, it is not unreasonable to consider that another part of our mind – let us call it the "up-in-the-sky-mind," mostly manifesting at the subconscious level – could access this more abstract domain of potentiality, where superposition states have not yet collapsed into more specific spatio-temporal instances.

The non-ordinary "up-in-the-sky-mind" could for instance be associated with those quantum-like properties of our brain that cannot be accounted for by the usual classical-computer brain models. It could also be related, more generally, to our bodies, considering that physical entities only have the appearance of objects moving in space and time, whereas at a more fundamental level they would manifest more like meaning-entities exploring a vaster conceptual reality. And of course, the non-ordinary "up-in-the-sky-mind" could also be related to more subtle/abstract structures yet to be put in evidence in experimental terms, which also could penetrate more deeply into the multidimensional fabric of the non-spatiotemporal realm.

So, in principle a physical entity can have access not only to superposition states over different regions of space, at a given time (creating correlations between causally separated events, thus introducing an element of *synchronicity* in our spatial reality), but also to superposition states over different times. The latter can produce the usual correlations in time, an expression of the fact that what happens in the present will generally affect the future (causality), but this certainly does not exhaust all possibilities. The spatiotemporal reality can only realize some of the possibilities in terms of 'connections based on meaning', and also the quantum correlations could be considered to be just a subclass of all possible correlations, resulting from all possible 'connections through meaning' characterizing our huge multidimensional reality.

Take the collection of pages of the world-wide-web as a metaphor for the different locations in space, each webpage representing a different spatial location. Beyond this structure, there is another web, much more abstract and much more fundamental, which is that of the *meaning content* associated with the ordinary world-wide-web. When you move from one page to another, by clicking on the different hyperlinks, you move in an already "collapsed reality," and can just explore a subclass of all possible *meaning connections*: those available as actually clickable hyperlinks. But these clickable hyperlinks are only a pale reflection of the entire meaning content of the web. In other words, when you are on a given webpage, its hyperlinks will connect to webpages that are still very close in meaning to its content. These hyperlinks constitute the possible futures of the webpage in question, explorable by an entity surfing the web in a causal-like way. What we have called the "down-to-earth mind" would only operate at the level of the webpages, and thus will only be able to predict the future based on the exploration of the existing "causal lines" associated with the processes of clicking on the available hyperlinks.

On the other hand, if we assume that there is a deeper level of our mind, having an access to the level of the meaning connections that have not, or not yet, formed a concrete hyperlink, then, by contemplating these hidden connections, it would be possible to make predictions based on this wider "bird perspective," which also includes superposition/entangled states between present and future happenings. And this may explain why human minds, in certain conditions, can actually experience precognitions. Therefore, these would not be so different after all from predictions based on causality: they would simply originate from the possibility of accessing a more abstract web of connections, beyond those that are describable in spatiotemporal/material terms.

Physicists, so far, have mostly studied correlations originating from states that are non-local in space (non-spatial), and are only starting to study correlations originating from states that are non-local in time (non-temporal). Quoting from (Musser, 2016): "Normally physicists think of [...] correlations as spanning space, linking far-flung locations in a phenomenon that Albert Einstein famously described as 'spooky action at a distance'. But a growing body of research is investigating how these correlations can span time as well. What happens now can be correlated with what happens later, in ways that elude a simple mechanistic explanation. In effect, you can have spooky action at a delay."

Parapsychic phenomena like the precognitive ones, could just be an example of phenomena produced by these 'entangled states in time', which from our parochial spatiotemporal perspective is perceived as "spooky actions at a delay," i.e., correlations that would be created out of meaning-connections that we could usually access only in a subconscious way, and which should be considered to be as real as the more ordinary connections based on cause-effect and action-reaction relationships.

To conclude, we have to observe that the quantum and relativistic revolutions have not yet been fully integrated in our modern worldvision, still predominantly based on spatiotemporal and mechanistic models that are certainly inadequate to account for all known phenomena. An extended worldview, which in part we have tried to delineate in this article, is however gradually gaining ground, although it is still perceived to be highly non-intuitive by the majority of physicists. It is this extended worldvision that we need to adopt if we want to have a chance at understanding the complexity and richness of our world, both at the physical and psychical (consciential) level. Then, many phenomena that currently appear to us as extraordinary, and therefore difficult to believe, may suddenly look very "down-to-earth." This would be so because we would have brought earth back to its original place: in the depths of the sky.

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On the conceptuality interpretation of quantum and relativity theories

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Abstract

How can we explain the strange behavior of quantum and relativistic entities? Why do they behave in ways that defy our intuition about how physical entities should behave, considering our ordinary experience of the world around us? In this article, we address these questions by showing that the comportment of quantum and relativistic entities is not that strange after all, if we only consider what their nature might possibly be: not an objectual one, but a conceptual one. This not in the sense that quantum and relativistic entities would be human concepts, but in the sense that they would share with the latter a same conceptual nature, similarly to how electromagnetic and sound waves, although very different entities, can share a same undulatory nature. When this hypothesis is adopted, i.e., when a conceptuality interpretation about the deep nature of physical entities is taken seriously, many of the interpretational difficulties disappear and our physical world is back making sense, though our view of it becomes radically different from what our classical prejudice made us believe in the first place.

1 Introduction

In 1924, *Luis de Broglie*, in his PhD thesis (De Broglie 1924), made one of the boldest moves in the history of modern physics. Following Planck and Einstein's introduction of a dual particle-like aspect associated with light waves, to "explain" their strange behavior in certain experiments, de Broglie, reasoning in a specular way, introduced the hypothesis that a wave-like aspect should also be associated with physical entities that, until that moment, were only considered to be corpuscles, like electrons, neutrons and protons. Like all new wild ideas, physicists were initially very unsure about the value of de Broglie's hypothesis, but fortunately Langevin had the foresight to send a copy of his thesis to Einstein, who was immediately conquered by the idea, so that de Broglie was ultimately granted his doctorate. The rest is history: a few years later, Davisson and Germer in the USA, and G.P. Thomson in Scotland, confirmed by means of diffraction experiments that electrons could also behave as waves. In 1929, Louis de Broglie was then awarded the Nobel Prize in physics for his discovery of the wave nature of electrons, which as we know laid the foundations of quantum mechanics, and in 1937 also Davisson and Thomson received the Nobel Prize, for their historical diffraction experiments.

The aim of the present paper is to discuss about a more recent "move à la de Broglie," which is also the result of a specular reasoning. The starting point is the new and booming research field known as *quantum cognition*, where the mathematical formalism of quantum mechanics was applied with unexpected success to model human concepts and their interaction with human minds, showing that we humans think and take decisions pretty much in a quantum-like way. This doesn't necessarily mean that our brains would be like *quantum computers*, exploiting the existence of quantum effects at the micro-level, but it certainly means that a quantum-like behavior is not the prerogative of the micro-entities, being instead a form of organization that can be found at different structural levels within our reality (Aerts and Sozzo 2015). Now, if the human conceptual entities are to be associated with a quantum-like behavior, and therefore possess a quantum nature, one can introduce the hypothesis that, the other way around, the micro-physical (quantum) entities should also be associated with a conceptual-like behavior, and therefore possess a conceptual nature similar to that of the human concepts. However, different from the wave-particle duality, the quantumness-conceptuality binomial would not be the expression of a relation of complementarity, but rather of a relation of similarity, in the sense that *quantumness* and *conceptuality* would just be two terms pointing to a same reality, or nature, which can manifest at different organizational levels within reality.

The above hypothesis, that quantum entities are conceptual, was proposed by one of us in 2009 (Aerts 2009, 2010a, b, 2013, 2014), and in the present work we will demonstrate its explicative power by reviewing some of the quantum situations in which it has been applied so far, among those considered to be not yet fully understood, or even not understandable. We will do the same for the interpretational difficulties of special relativity theory, thus showing that the *conceptuality interpretation* really represents a possible fundamental step forward in our understanding of the stuff our world is made of, and a candidate for the construction of a coherent framework for both quantum and relativity theories, and maybe also evolutionary theories (Aerts and Sassoli de Bianchi 2018). But before doing so, some words of caution are necessary. From the hypothesis that quantum entities would be conceptual entities carrying meaning and exchanging it with pieces of ordinary matter, a *pancognitivist* view naturally emerges (Aerts and Sassoli de Bianchi 2018), where everything within our reality participates in cognition, with human cognition being just an example of it, expressed at a specific organizational level. This, however, is not meant to be interpreted as an anthropomorphization of reality, because human cognition is to be considered as a much younger and hence still rather unsophisticated form of that more fundamental conceptual structure constituting the global reality.

There is also no connection at all with any type of idealistic philosophical views, where physical theories would be considered to be mere theories of human mental content. Quite on the contrary, the conceptuality interpretation is a genuine realistic view, where conceptual entities are seen as entities that can be in different states and be subjected to measurement processes, which are processes not only of *discovery* (of the properties that were already actual), but also of *creation* (of those properties that were only potential prior to the measurement and could become actual through its execution). Also, the conceptual substance forming our global reality is not even necessarily connected to the human cognition, its existence being certainly independent of it, i.e., even when us humans, as a cognitive species, had not yet come into existence on the surface of planet Earth, the fundamental conceptual substance forming our global reality was already there, because also its quantum aspects were already there. To make even more clear the realistic stance underlying our conceptuality interpretation, if the dinosaurs would not have become extinct (probably due to the impact of an asteroid) and would have further evolved their cognitive talents, they could easily have been them the first to explore the conceptual layer existing within their species, in a similar way as they might have also have been the first to discover the quantum nature of the micro world.

Having said this, and before proceeding in the next sections by describing how the conceptuality interpretation can explain different quantum and relativistic phenomena, it is interesting to reflect for a moment about the reasons why quantum physics has remained so far so difficult to understand, which is also the reason why so many interpretations have seen the day since it was fully formulated in the thirties of the past century. The case of relativity theory is only apparently different, as the majority of physicists seem to cultivate the belief that relativity would be well understood, or at least much better understood than quantum mechanics, which in our view is only the fruit of a misconception, as we will emphasize later in the article. A first important point to consider is that the very fact that numerous quantum interpretations still exist today can be seen as the sign that none of them has been able to provide so far those notions that would capture, in its entirety, the reality that quantum theory aims to describe, and therefore obtain a general consensus. We believe that one of the reasons for their failure is the fact that most of them only try, somehow nostalgically, to interpret the mathematical quantum formalism in terms of classical spatiotemporal notions.

To better explain what the fulcrum of the problem is, when one tries to understand quantum (and relativistic) entities, let us use a metaphor. During the eighteenth century, the first British settlers who landed on the Australian continent were confronted with a totally new territory, both for the uses and customs of the natives, the Aborigines, and for the mysterious flora and fauna that populated those distant lands. Among Australian animals there was one in particular that struck the imagination of the settlers. Every now and then they could see it in the vicinity of the watercourses, but being shy it was difficult to see it clearly. When they could have a glimpse of it from the front, seeing its flat beak and its two palmed feet, they probably exclaimed: “It’s a duck!” But then, when it turned around and ran away, they realized that it had not two, but four paws, and a dense fur. So, they probably also exclaimed: “No, it’s a mole!” And by dint of exclaiming that: “It’s a duck!... No, it’s a mole!... No, it’s a duck!... No, it’s a mole!...” in the end they decided to call it a *duckmole*! (Our little story is of course a caricature). In other words, they baptized this odd animal with a paradoxical name, obtained by the composition of the names of two different animals. Such a designation, of a dualistic nature, was clearly only provisional, since no animal can simultaneously be a duck and a mole, and when they finally managed to observe it more closely and more attentively, they realized that it was neither, but something completely different, so finally the animal got a name of its own: *platypus*![1]

The above curious anecdote was used by *Jean-Marc Levy-Leblond* (1999) to illustrate the situation of physicists at the beginning of the past century, who like the Europeans settlers were confronted with entities—the microscopic ones, such as photons and electrons—whose appearance could change depending on the experimental settings, sometimes being observed as particles (moles) and other times as waves (ducks). And again, by dint of exclaiming that: “It’s a particle!... No, it’s a wave!... No, it’s a particle!... No, it’s a wave!...” in the end they also decided to provisionally denote them *waveparticles*, *wavicles*, etc., (Bunge 1999; Lévy-Leblond and Balibar 1997), i.e., to talk about them in terms of a *wave-particle duality*. But in the same way a platypus is neither a duck nor a mole, and certainly not

[1] Prior to the arrival of the European settlers, Aboriginal people had many names for the animal, including *boondaburra*, *mallingong* and *tambreet*. The first scientific description of the platypus (*ornithorhynchus anatinus*) is attributed to the English botanist and zoologist *George Shaw*, whose first reaction was to believe the specimen to be a hoax, made of several animals sewn together.

simultaneously a duck and a mole, a microscopic quantum entity is also neither a particle nor a wave, and certainly not simultaneously a particle and a wave. The waveparticle dualistic designation is in fact only the result of a fleeting observation of their behavior, and if one takes the time to observe them with more attention, it becomes clear that what they truly are is "something else," something completely different from the discrete and local notion of a particle as well as from the continuous and extended notion of a wave, since both of these notions are spatial, while one of the most salient features of the microscopic quantum entities is precisely that of not being representable as entities permanently present in space (or spacetime). In other words, we know what quantum entities certainly are not: they are *non-spatial* entities (and more generally, as we are going to also discuss, *non-spatiotemporal* entities).

However, knowing what a microscopic quantum entity is not, does not tell us what it is, i.e., what its nature truly is. The same was true for the previous example of the platypus: knowing what it was not, was not sufficient to determine its nature, which is the reason why a controversy lasted for quite some time among European naturalists, when they discovered the unusual characteristics of the animal.[2] Understanding the nature of a quantum entity is fundamental because the behavior of a physical entity can appear to us very strange, if not incomprehensible, if we believe it is something that it is not, whereas its behavior may all of a sudden become perfectly normal and fully understandable if we can correctly identify its nature. In that respect, it is important to emphasize that a physical theory requires not only a mathematical formalism, but also a network of physical concepts coherently relating to the latter and capable of providing a meaningful physical representation of the reality the theory aims to describe (De Ronde 2018). And of course, among these physical concepts the most crucial one is that identifying the nature of the physical entities the theory is about. For instance, before the advent of quantum mechanics, the concept of *particle* (or *corpuscle*) was fundamental in order to make sense of the

[2] Today the platypus is classified as a *monotreme*: a mammal that can lay eggs, with the male also having a spur on the hind foot that delivers a venom capable of causing severe pain to humans, and with many other structural differences compared to common mammalians.

other notions associated with the theory (of classical mechanics), like those of position, velocity, mass, etc., which in turn were associated with specific mathematical objects in the formalism.

So, to make sense of quantum mechanics, the first thing one needs to do is to find a notion specifying what the nature of a micro-physical entity is. We know it is not a particle notion, or a wave notion, nor a waveparticle notion, so, what is it? The standard answer is that we don't have nothing valid at hand to represent the nature of a quantum entity, but, that's it? As *Arthur Conan Doyle* used to point out more than once, in his Sherlock Holmes stories, sometimes the best place to hide something is to keep it in plain sight. And according to the conceptuality interpretation, what has always been in plain sight, but precisely for that was very hard to notice, is that the notion one should use to represent the nature of a quantum entity, and make full sense of its behavior, is the very notion of *concept*! In other words, human concepts would not be the only category of conceptual entities with which we humans have interacted: the so-called microscopic quantum entities would form another category of conceptual entities, much more ancient and structured than our human ones, and as soon as we reset our mental parameters and start thinking of, say, an electron, not as an object but as a conceptual entity, most of the mystery of its quantum behavior disappears, as we are now going to show by considering different physical situations.

2 The double-slit experiment

Richard Feynman used to say that the double-slit experiment has in it the heart of quantum mechanics and contains the only mystery. Certainly, it contains part of the mystery, so let us start by describing this experiment to show how it can go away, if we only start thinking of the micro-physical entities interacting with double-slit barrier—let us assume they are electrons—not as particles, or waves, but as conceptual entities. For this, we begin by recalling why the double-slit experiment is impossible to explain in any classical way. The reason is simple: the localized impacts on the detector screen seem to show that the entities in question are particle-like. On the other hand, the fringe pattern one observes, when multiple impacts are collected, reveals that what traverses the double-slit is more like a wave phenomenon, able to create interference effects (see Figure 1). And since a wave is not a particle, and *vice versa*, the observed behavior of the electrons cannot be consistently explained.

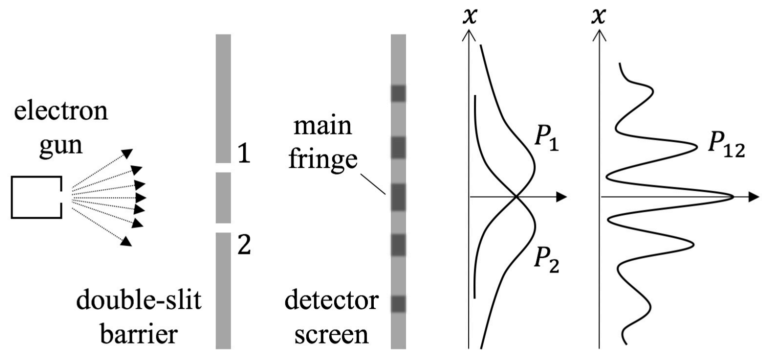

Figure 1 In the double-slit experiment an electron source fires the electrons towards a barrier having two slits. If slits 1 is open and slit 2 is closed, the probability distribution for detecting an electron at a distance x from the center of the detection screen is P_1. If slits 2 is open and slit 1 is closed, the probability distribution is P_2. If both slits are open, the probability distribution P_{12} is not proportional to the sum of P_1 and P_2, as one would expect if the electrons were particles, but is a more complex function describing a fringe interference pattern, with the main fringe being the one at the center of the detection screen.

More precisely, if they would be like small projectiles, then a *compositional* interpretation of the experiment should be possible, with the pattern of impacts obtained when both slits are open being deducible from the patterns of impacts obtained when these are opened one at a time, instead of simultaneously. This means that the probability $P_{12}(x)$ of having an impact at a point x of the detection screen, in the situation where the two slits are open, should be given by the uniform average of the probabilities $P_1(x)$ and $P_2(x)$ of having an impact at that same point when only slit 1 or only slit 2 are open, respectively, i.e.,

$$\bar{P}_{12}(x) = \frac{1}{2}[P_1(x) + P_2(x)]$$

But since we generally have $P_{12}(x) \neq \bar{P}_{12}(x)$, even though the electrons *appear* to be corpuscular, as they leave traces on the screen in the form of point-like impacts, they cannot be such, as the obtained complex fringe pattern demonstrates. Note that the one-slit probability distributions probabilities $P_1(x)$ and $P_2(x)$ are compatible with the hypothesis that the electrons would be entities of a corpuscular nature. It is really when both slits are simultaneously open that the distribution of impacts on the detection screen becomes incompatible with the corpuscular assumption, being no longer deducible as a uniform average of the one-slit distribution probabilities.

Reasoning in probabilistic terms, there will be points x on the detection screen where the probability of observing an electron will differ sensibly from the value given by the uniform average $\bar{P}_{12}(x)$, in the sense that there will be points of *overexposure* [corresponding to a probability *overextension*: $P_{12}(x) > \bar{P}_{12}(x)$], and points of *underexposure* [corresponding to a probability *underextension*: $P_{12}(x) < \bar{P}_{12}(x)$], meaning that one has to correct the uniform average by introducing a third term $I(x)$, an *interference contribution* responsible for these overextension (constructive interference) and underextension (destructive interference) effects:

$$P_{12}(x) = \bar{P}_{12}(x) + I(x)$$

Let us now consider the hypothesis that the electrons are conceptual entities, i.e., entities behaving in a way which is similar to how human concepts behave. And let us also assume that the measuring apparatus, and more specifically the screen detector, is an entity sensitive to the meaning carried by the electrons and able to answer questions when the latter are addressed in operational terms, i.e., by enacting them through the construction of a specific experimental arrangement. Of course, the screen detector mind-like entity does not speak our human language, and will only communicate by means of signs that are the electrons' traces of impact on its surface, which we have to correctly interpret, and for this we have to understand what is the meaning that is attached to the impacts appearing in the different positions. Now, the questions the screen-mind entity is possibly answering, by means of its "pointillistic language," are here the following three:

(a) "What is a good example of an impact point of an electron passing through slit 1?"
(b) "What is a good example of an impact point of an electron passing through slit 2?"
(c) "What is a good example of an impact point of an electron passing through slit 1 or 2?"

These three questions can be addressed in practical terms by having only slit 1 open, only slit 2 open, and both slits open, respectively. Of course, the electron conceptual entity will then be in a state that depends on the configuration of the barrier. When only slit 1 is open, it will be in a state ψ_1, corresponding to the conceptual combination *The electron passes through slit 1*. When only slit 2 is open, it will be in a state ψ_2, corresponding to the conceptual combination *The electron passes through slit 2*. And when both slits are open, it will be in a state $\psi_{1,2}$, corresponding to the conceptual combination *The electron passes through slit 1 or 2*.[3]

If the above states are represented by complex vectors in a Hilbert space, one can easily recover the interference pattern at the detection screen by representing $\psi_{1,2}$ as a normalized superposition of

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[3] The notion of "passing through" remains a very human way of conceptualizing the question addressed to the measuring apparatus. Indeed, when we say "passing through," or even "impact point," we are already attributing to the electron spatial properties that it does not necessarily have. In other words, we are already looking at things from the bias of our spatial prejudices. On the other hand, if "passing through" is more generally understood as a way to express the fact that the only regions of space occupied by the barrier where there is a zero probability of absorbing the electrons are those of the two slits (when they are open), then the notion of "passing through" can still be used to conveniently describe the experiment in a way that our human minds can easily understand. A more general and probably more correct way of formulating the above three questions would be:

(a) "What is a good example of an effect produced by an electron interacting with the barrier having only slit 1 open?"
(b) "What is a good example of an effect produced by an electron interacting with the barrier having only slit 2 open?"
(c) "What is a good example of an effect produced by an electron interacting with the barrier having both slit 1 and 2 open?"

ψ_1 and ψ_2, i.e.,

$$\psi_{1,2} = \frac{1}{\sqrt{2}}(\psi_1 + \psi_2)$$

Then, the probability density $P_1(x)$ [resp., $P_2(x)$] that the screen-mind provides the answer x to question (a) [resp., (b)] is $P_1(x) = |\psi_1(x)|^2$ [resp., $P_2(x) = |\psi_2(x)|^2$], whereas the probability density for x to be selected as a good example of an electron passing through slit 1 or 2 [question (c)] is:

$$P_{1,2}(x) = \left|\psi_{1,2}(x)\right|^2 = \frac{1}{2}|\psi_1(x) + \psi_2(x)|^2$$
$$= \frac{1}{2}[|\psi_1(x)|^2 + |\psi_2(x)|^2] + \Re\psi_1^*(x)\psi_2(x)$$

where $I(x) = \Re\psi_1^*(x)\psi_2(x)$ is the interference contribution, accounting for the overextension and underextension effects, and the symbol $\Re$ denotes the real part of a complex number. This is of course the well-known quantum mechanical rule saying that when we are in the presence of alternatives (slit 1 or 2), the probability amplitude is obtained by the normalized sum of the probability amplitudes for the alternatives considered separately. But what we want now to understand is the emergence of this fringe pattern from the conceptuality hypothesis viewpoint. In other words, we want to understand the cognitive process operated by the detection screen, when viewed as a mind-like entity answering the above three questions.

First of all, we have to observe that such cognitive process cannot be deterministic. Indeed, the specification "passing through a slit" is not sufficient to describe a unique trajectory in space. This is so also because being the electron a conceptual entity, it cannot be attached with *a priori* spatial properties. These will have to be acquired by interacting with the apparatus, so as to give a sense to the very notion of "passing through." And since there are many ways in which a spatial entity is able to pass through a slit, the screen-mind will have to choose from among several possibilities, and choosing one among these possibilities is a *symmetry breaking* process whose outcomes cannot be predicted in advance, which is the reason why every time the question is asked the answer (the trace of the impact on the screen) can be different. However, answers cannot be totally arbitrary, as is clear that the question specifies that the electron passes, for example in case of question (a), through slit 1. So, the screen-mind will certainly manifest a greater propensity to respond by means of an impact point located in a position in proximity of slit 1, which means that the symmetry breaking process will be a weighted one, with some outcomes having greater probability than others (more will be said about measurements in Section 9). Of course, things get more interesting when we consider question (c), as in this situation not only there are many possibilities about how the electron will pass through either slit, but also about which slit, 1 or 2, it will pass through. Confronted with this situation, the screen-mind will thus have to select those answers that best express this double level of uncertainty, producing an impact point that will be typical of an electron conceptual entity having acquired spatial properties and passing through slit 1 or 2. And when the question is operationally asked several times, the result will be the typical fringe structure shown in Figure 1.

Let us delve into the screen-mind to try to understand how such fringe structure can emerge. For this, let us concentrate on its most salient feature: the central fringe, which is the one with a higher density of impacts, located at equal distance from the two slits. This is where the screen-cognitive entity is most likely to manifest an answer, when subjected to question (c). To understand why, we can observe that an impact in the region of the central fringe corresponds to a situation of maximum doubt regarding the slit the electron would have used to cross the barrier, or even the fact that it would necessarily have passed through one or the other slits, in an exclusive manner. Therefore, it constitutes a perfect exemplification, in the form of an impact point on the screen, of the concept "an electron passing through slit 1 or 2." Now, if the region in between the two slits is a region of overextension, the two regions opposite the two slits are instead regions of underextensions, showing a very low density of impacts. To understand why, we can observe that an impact in the regions facing the two slits would not make us doubt about the slit through which the electron has passed. In other words, an impact point in the two regions opposite the slits would constitute a very bad exemplification of the concept "an electron passing through slit 1 or 2." Moving then from these two regions away from the center, we will be back again in a situation of doubt, although less perfect than that expressed by the central region, so regions of overextension will manifest again, but this time less intense, and then again regions of underextension will come, and so on, producing in this way the typical fringe pattern observed in experiments.

Considering the above conceptuality explanation of the double-slit experiment, we see that the wave aspect associated with electrons (mathematically described by the wave function $\psi_{1,2}$, evolving according to the Schrödinger equation), is just a convenient way to model, by means of constructive and destructive interference effects, the different overextension and underextension effects that result from the cognitive (symmetry breaking process) through which a good (concrete) exemplar for an abstract conceptual entity is each time provided, when the interrogative context forces the electronic conceptual entity to enter the spatiotemporal theater, by means of a localized impact on the screen. Of course, this impact should not be mistaken as a trace left by a corpuscular entity with a well-defined trajectory in space, as it will be better explained in the following sections. Now, to confer more credibility to the above narrative, and considering that an electron and a human concept are assumed to share the same conceptual nature (in the same way an electromagnetic wave and an acoustic wave, even though they are different physical phenomena, can share the same wavy nature), one should be able to also show that human minds are able of producing similar interference figures, when subjected to interrogative contexts that confront them with genuine alternatives. This is indeed the case: human minds, when interacting with concepts, will generally produce overextension and underextension effects having a very complex pattern, in fact much more complex (less symmetric) than those produced by screen-minds interacting with electrons (or photons). Let us very briefly describe an experiment where this has been explicitly demonstrated, referring the interested reader to Aerts (2009) and Aerts and Sassoli de Bianchi (2017a) for the details.

In the eighties of last century, the cognitive psychologist *James*

Hampton conducted an experiment where 24 exemplars of *Food*[4] were submitted to 40 students, asking them if they were typical (i.e., good examples) of a (Hampton 1988):

(a) *Fruit*;
(b) *Vegetable*;
(c) *Fruit or vegetable*.

These different exemplars of *Food* play here the same role as the different locations x on the detection screen, in the double-slit experiment, with the concept *Fruit* (resp., *Vegetable*) playing the role of slit 1 (resp., slit 2). If the decision-making process of the students, when subjected to question (c), would be of a sequential kind (they first choose between *Fruit* and *Vegetable* and then, if they chose the former, they select a good example of *Fruit*, and if they chose the latter, they select a good example of *Vegetable*), then the probability of selecting a given exemplar of *Food* should correspond to the uniform average of the probabilities describing the situations of questions (a) and (b). But this is not what Hampton's data reveal, which contain instead a complex pattern of overextension and underextension effects. When these data are represented in a quantum-like way, using two two-dimensional functions interpolating the outcomes of questions (a) and (b), then a normalized superposition of these two functions to interpolate the data of question (c), a complex interference figure is revealed, reminiscent of those obtained in the phenomena of birefringence (Aerts 2009; Aerts and Sassoli de Bianchi 2017a) (see Figure 2).

We conclude this section by an important remark. In our discussion, we made a distinction between the detector screen, playing the role of the structure sensitive to the meaning carried by the electrons, and the barrier, playing the role of the structure allowing the three questions (a), (b) and (c) to be addressed in operational terms, when slit 1, slit, 2, and both slits are open, respectively. This distinction is however not fundamental and was just used to obtain a stronger analogy with our typical human experience, when we distinguish the mind answering a question from the process of

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[4] These are: *Almond, Acorn, Peanut, Olive, Coconut, Raisin, Elderberry, Apple, Mustard, Wheat, Ginger root, Chili pepper, Garlic, Mushroom, Watercress, Lentils, Green pepper, Yam, Tomato, Pumpkin, Broccoli, Rice, Parsley, Black pepper*.

addressing a question to it, for instance orally or in writing. In fact, the entire structure of the experimental apparatus should really be interpreted as the mind-like entity, as is clear that not only the screen but also the other material parts, in particular the barrier, interact as a whole with the electrons' conceptual entities. So, a more correct image consists in saying that the structure of the entire apparatus mind-like entity changes depending on the question that is being asked. More precisely, the effect of asking question (a) [resp., (b) and (c)] is the opening of slit 1 (resp., slit 2 and both slits) at the level of the barrier, and the actual answering of the question is the process of having the electron conceptual entity entering it and leaving a trace on the detector screen.

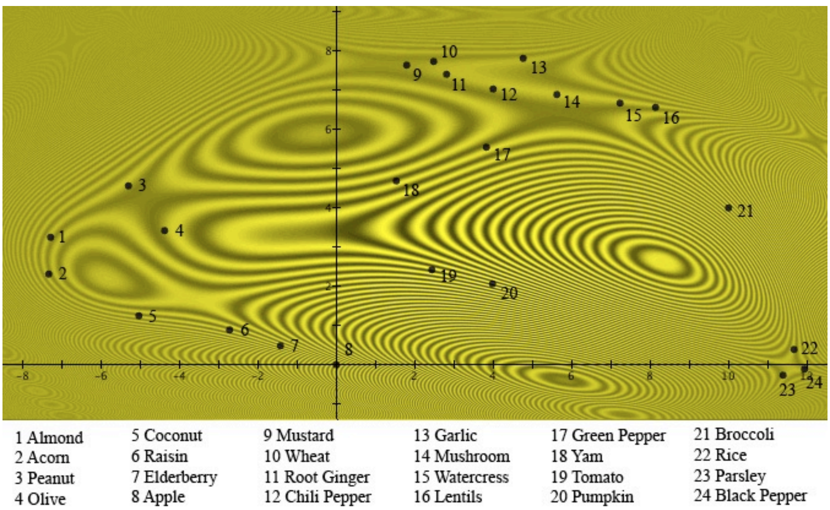

Figure 2 The interference-like figure describing the overextension and underextension effects contained in Hampton's data, when the participants had to select exemplars representative of the disjunction *Fruit or vegetable*. For more details about how this figure was obtained, see Aerts (2009).

Having analyzed the double-slit experiment, we want to consider in the next section another paradigmatic quantum experiment that remains impossible to understand if one does not give up the prejudice that the micro-physical entities would be particles or waves, i.e., spatiotemporal phenomena, and becomes instead very easy to explain if one assumes that they are conceptual (meaning) entities.

3 Delayed-choice experiment

In 1978, Wheeler considered the following experiment (Wheeler 1978). A quantum entity, say an electron, enters an apparatus like the previously described double-slit one, with the difference that its arrangement can be changed at the last moment, before the electron is finally detected. The variable arrangements that are considered are two: a wave arrangement, like the one used in a typical double-slit experiment, which gives rise to overextension and underextension effects, and a particle arrangement, corresponding to the situation where the detection screen is removed and replaced by a second detection screen, located at a greater distance, so that the impacts detectable on it become compatible with a classical particle-like description (no overextension or underextension effects); see Figure 3.

More precisely, since the apparatus causes the wave function's components coming from the two slits to diverge, they will not anymore superimpose when they arrive at the place where the second (fixed) screen is present, so that the traces of the impacts on it allow to determine with no ambiguity the wave function component they are associated with, i.e., which path was followed by the electron, if interpreted as a particle. The experimental setting is however such that the arrangement can be changed extremely rapidly, and the result of the many experiments so far conducted is that though the arrangement is changed at the very last moment, the electrons (or any other micro-physical quantum entities) behave as if it was present since the very beginning.

Experiments of this kind [see for instance Jacques et al. (2007)] demonstrate the inadequacy of the wave-particle duality. As a matter of fact, if the electron quantum entity would behave as a wave (i.e., as a spatial entity passing through both slits) or as a particle (i.e., as a spatial entity passing either through slit 1 or slit 2), depending on the experimental arrangement, then, when the latter is changed at the last moment, the electron (assumed to be an entity propagating through space) should have left already the double-slit barrier region, and the delayed change should not be able to affect its prior wave or particle behavior.

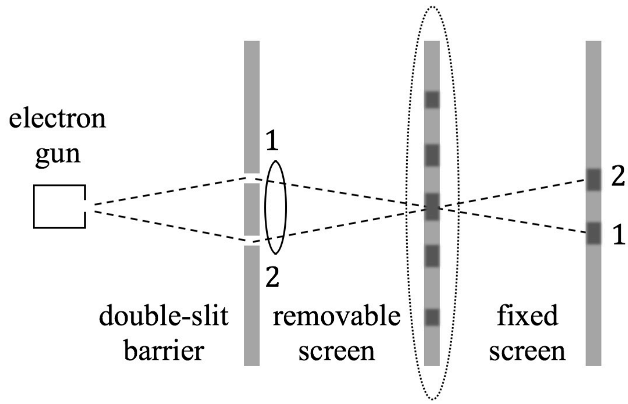

Figure 3 A schematic diagram of a delayed-choice experiment, where one of the two detection screens is removable, so that a wave-like or particle-like context can be created by either leaving it in place or removing it, respectively. The lens element close to the double-slit barrier makes the wave function components coming from the two slits to slightly diverge, so there will be relevant interference effects only at the location of the removable screen, but not at the more distant location of the fixed screen. This means that the latter will not show a fringe pattern, but only two distinct and equivalent regions of impact, which can be associated with electrons emerging either from slit 1 or from slit 2.

This however is not what is observed in the experiments, where everything happens as if the electron would have "delayed its choice" (from which the name that was given to these experiments) of manifesting either as a wave-like phenomenon or as a particle-like phenomenon, until the final arrangement is decided. Facing the implications of these experiments, Wheeler famously affirmed the following (Wheeler 1978): "Then let the general lesson of this apparent time inversion be drawn: 'No phenomenon is a phenomenon until it is an observed phenomenon.' In other words, it is not a paradox that we choose what shall have happened after 'it has already happened.' It has not really happened, it is not a phenomenon, until it is an observed phenomenon."

If by "phenomenon" we understand a "spatial phenomenon," then we can only agree with Wheeler's statement, which indicates that we cannot understand the behavior of an electron by depicting it as a spatial entity, be it a wave, a particle, or a waveparticle. In other words, what these experiments show is that electrons, and any other micro-physical entities, are *non-spatial* entities: when the gun fires an electron towards the double slit barrier, one should not imagine it as a wave or a particle propagating in space, but as a more abstract entity that is only drawn into space at the moment of its actual detection, either by the removable screen or by the fixed screen, depending on the final selection. Of course, the electron exists also prior to its detection, though not as an entity having already acquired spatiotemporal properties. Again, this is typical of the behavior of a conceptual entity whose state can change from a more abstract to a more concrete one, when interacting with a (mind-like) structure sensitive to the meaning it carries.

Let us consider once again the conceptuality hypothesis, to see how the apparent delayed-choice behavior of the electron becomes not only perfectly understandable, but also corresponds to what we would expect. As described in the previous section, the question that is being asked is: "What is a good example of an impact point of an electron passing through slit 1 or 2?" An answer to this question will be manifested either by the removable screen-mind, if maintained in place, or by the fixed screen-mind, if the former has been removed. These two cognitive entities, however, will encounter the electrons' conceptual entities in different states, because of their distinct spatial locations. From the perspective of the removable screen, which is closer to the double-slit barrier, the converging lens has no relevant effects, so the state $\psi_{1,2}$ of the electrons can be conveniently described by the conceptual combination: *The electron passes through slit 1 or 2*. On the other hand, since the converging lens produces a relevant effect for the farther away fixed screen, it will interact with the electrons in a different state $\psi'_{1,2}$, which can be described by the conceptual combination: *The electron passes through slit 1 or 2 and is subsequently strongly deviated from its trajectory by a converging lens*. These states being different, the meaning carried by the electron in the two situations is also different, so that the removable screen-mind will answer the question in the way described in the previous section, with a complex fringe pattern having a central major fringe, whereas the fixed screen will answer by randomly considering either an upper spot, associated with slit 2, or a lower spot, associated with slit 1 (see Figure 3).

But why now a central spot is not anymore a good exemplar for expressing the doubt regarding which slit an electron has passed through? The reason is simple to understand: because of the presence of the converging lens, and the distance of the fixed screen, the state $\psi'_{1,2}$ of the electron can now be described, in more synthetic terms, by the conceptual combination: *The electron passes through slit 1 either/or 2*. In other words, the "or" has been replaced by an "exclusive-or" (xor), conveying the meaning that the electron can pass through slit 1 or slit 2, but not through both of them. So, the fixed screen has to answer the same question of the removable screen, but with the additional information that the electrons do not pass through both slits simultaneously. This means that a central point on the screen will not be anymore a good example of the situation, as a central point expresses a much deeper form of doubt: one where not only we don't know the slit through which the electron has passed through, but also if it has passed through only one of them or both of them. Now, since the slit through which the electron passes through remains unspecified, the only option for the fixed screen-mind, to answer consistently, is to produce a point impact either in a location compatible with the situation of an electron passing through slit 1, 50% of the times, or in a location compatible with the situation of the electron passing through slit 2, the other 50% of the times, which is exactly what is observed in experiments. Using again the Hilbert space formalism, we now have:

$$P'_{1,2}(x) = \left|\psi'_{1,2}(x)\right|^2 = \frac{1}{2}|\psi'_1(x)|^2 + \frac{1}{2}|\psi'_2(x)|^2$$

i.e., the two alternatives are non-interfering, compatibly with a classical (compositional) description.

4 Heisenberg's uncertainty relations

Coming back for a moment to the wave-particle duality, and assuming that an interference pattern would be indicative of a wave, and the absence of it would be indicative of a particle, experiments like the one described in the previous section are usually interpreted by saying that the behavior of a quantum entity, like an electron, is determined by the type of measurement we perform on it. This is certainly correct, but only if we understand that the determination arises in the moment the quantum entity is actually detected, and not before, and this also means that if we do not want to abandon a realistic view of our physical reality, we have to accept that a micro-physical entity, prior to its detection, is usually neither in a wave nor in a particle state, but in a condition that cannot be associated with any specific spatial property. The *de Broglie-Bohm theory* can certainly offer an alternative description here, as it assumes that a quantum entity is the simultaneous combination of both aspects: a particle and a (pilot) wave (Norsen 2006). However, if considered as a tentative to preserve spatiality, the theory, as is well-known, faces a serious problem when dealing with more than a single entity, as the pilot wave (or quantum potential) cannot then be described as a spatial phenomenon, hence the interpretational problem remains, and in a sense get even worse.

If we understand conceptual entities as meaning entities that can be in different states (each state specifying the actual meaning carried by the conceptual entity), which can change either in a predictable way, when they are subjected to deterministic contexts, or in an unpredictable way, when they are subjected to indeterministic ones, like interrogative (measurement) contexts, it immediately follows that, by definition of what a state is, a conceptual entity in a given state cannot be at the same time in another, different state. We are of course stating the obvious, but this is really what is at the foundation of Heisenberg's uncertainty principle. Consider the human concept *Animal*. When we use a single word to indicate this concept, we can say that it describes the most abstract of all its states, associated with a perfectly neutral (tautological) context, just conveying the meaning that: *The animal is an animal*. Let us look right away at a parallel between the human concept *Animal* and a microphysical entity like an electron, which according to the conceptuality interpretation also possesses a conceptual nature. Non-relativistic quantum theory does not describe in formal terms the state of an electron in the condition of just being an electron. We usually describe an electron in contexts were the electron has already acquired some more specific properties, which in the theory are mathematically described by the given of a (Hilbert space) vector, or a density matrix.

Consider then the following concepts: *Dog*, *Cat*, *Horse*, etc. They are all specific examples of *Animal*, hence, they specify different possible states of the animal-concept, and more precisely the states conveying the meanings: *The animal is a dog*, *The animal is a cat*, *The animal is a horse*, etc. In other words, the concept *Animal* can be in different states and the above are of course still examples of very abstract states, if compared to states that are determined by contexts that put for instance the *Animal* concept in a one-to-one relation with a well-defined entity of our spatiotemporal theater. So, the conceptual combinations: *The Labrador dog named Esmerelda owned by actress Anne Hathaway*, *Cameron Diaz' white cat named Little Man*, *The race horse named Lexington who set a record at the Metaire Course in New Orleans*, etc., are much more concrete states of the concept *Animal*. A concept can thus be in different states, but certainly cannot simultaneously be in two different states, and some states are maximally abstract, others maximally concrete, and in between there are states (the majority of them) whose degree of abstraction is intermediary, like for instance the state described by the conceptual combination: *A cat owned by a celebrity* (Mervis and Rosch 1981; Rosch 1999). This means that a concept cannot be in a state that is maximally abstract and at the same time maximally concrete, and this is nothing but the conceptuality version of Heisenberg's uncertainty principle (see Figure 4).

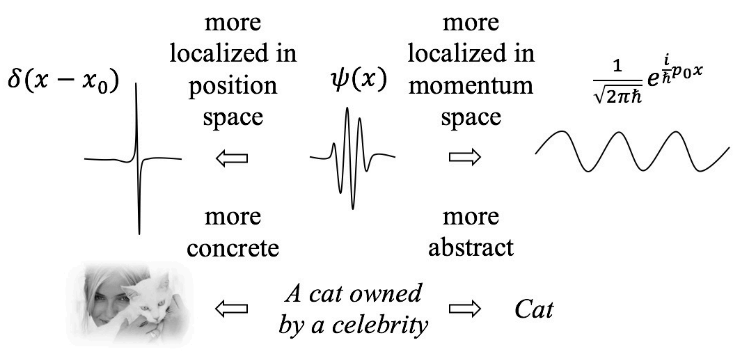

Figure 4 A schematic diagram describing the localized in space versus localized in momentum (opposite) directions which, according to the conceptuality interpretation, correspond to the concrete versus abstract directions.

In the case of an entity like an electron, a maximally concrete state corresponds to the electronic entity being maximally localized in our three-dimensional space, while a maximally abstract state corresponds to it being maximally delocalized, i.e., to an electron being maximally localized in momentum space. In handbooks of quantum mechanics, Heisenberg uncertainty principle is usually stated by using the standard deviations of two non-commuting observables, like the position q and momentum p observables. The typical result is that the product $\sigma_q\sigma_p$ of their standard deviations must be bounded from below by a given value, for instance $\hbar/2$. The standard deviation σ_q has here to be interpreted as a measure of the degree of concreteness of the state in which the electron micro-entity is, with $\sigma_q = 0$ corresponding to a condition of maximum concreteness (i.e., maximum localization in position space) and $\sigma_q = \infty$ of minimum concreteness. Similarly, σ_p has to be interpreted as a measure of the degree of abstractness of the state in which the electron is, with $\sigma_p = 0$ corresponding to a condition of maximum abstractness (i.e., maximum localization in momentum space) and $\sigma_p = \infty$ of minimum abstractness. It is then clear that the product $\sigma_q\sigma_p$ must be bounded from below, as we cannot have simultaneously a situation of maximum concreteness ($\sigma_q = 0$) and maximum abstractness ($\sigma_p = 0$), or situations where concreteness (resp., abstractness) would be maximal and abstractness (resp., concreteness) would be intermediary (i.e, with a finite standard deviation). However, the product $\sigma_q\sigma_p$ should be also bounded from above, as we cannot simultaneously have a situation of minimum concreteness ($\sigma_q = \infty$) and minimum abstractness ($\sigma_p = \infty$), or situations where concreteness (resp., abstractness) would be minimal and abstractness (resp., concreteness) would be intermediary (i.e., with a finite standard deviation). And in fact, a reverse version of Heisenberg's uncertainty relations can also be derived, as was recently done (Mondal et al. 2017), in accordance with what the conceptuality interpretation indicates.

5 Explaining non-spatiality (non-locality)

According to the above discussion, Heisenberg's (direct and reversed) uncertainty relations should not be considered to be the result of a lack of precision about how observables are measured in the laboratory, or the fact that measurements can alter the state of the measured entity (as was initially considered by Heisenberg in his semiclassical microscope reasoning). They would instead be an ontological statement describing the necessary tradeoff between concreteness and abstractness, resulting from the fact that, at the ontological level, quantum entities would be conceptual (meaning) entity. So, the *non-locality* of a micro-entity like an electron, which should be more properly denoted *non-spatiality*, would express the fact that most of the electron's states are abstract ones (with different degrees of abstractness), with the subset of the maximally concrete ones only corresponding to those describing specific localizations in space. Accordingly, the classical notion of *object* (here understood as a spatiotemporal entity) corresponds to a conceptual entity that can remain for a sufficiently prolonged time in a maximally concrete state, which means that objects (classical entities) would just be limit cases of conceptual entities immersed in deterministic contexts that allow them to remain maximally concrete for a long time.

A possible criticism of the above explanation of Heisenberg's uncertainty relations would be that there is nothing truly fundamental in our human distinction between abstract and concrete concepts, as is clear that what we call concrete concepts are precisely those associated with the objects we have interacted with, in the course of our evolution on the surface of this beautiful "pale blue dot." It is certainly true that physical objects have played an important role in the way we humans have formed our language and have created more abstract concepts, for instance when in the need of indicating an entire category of objects instead of just a member of a category. So, in this human historical line of going from the concrete to the abstract, the most concrete concepts are those specifying spatiotemporal entities (objects), like in the conceptual combination: *This item that I'm presently holding in my hands*, and the most abstract ones are those indicated by terms like *Entity*, *Thing*, *Stuff*, etc., with all the other concepts lying in between them, as regards their degree of abstractness/concreteness (see Figure 5). This human (parochial) line is the one typically considered in semiotics and psychology, which is the reason why psychologists use the term *instantiation* to denote a more concrete form (a more concrete state) of a given concept. This term mostly refers to the actualization in time of an exemplar of a more abstract concept, like when *Apple* is chosen as an exemplar of *Fruit*, but of course one could also use the term *spatialization* (or *spatiotemporalization*), in addition to instantiation, when the exemplar in question is an object also existing in space. One should however bear in mind that a human concept, even when indicating an ordinary object, is not an object, and *vice versa*, a physical object is not a human concept, although the latter can be put in a correspondence with the former and the former, according to the conceptuality interpretation, is a conceptual entity in a maximally concrete state.

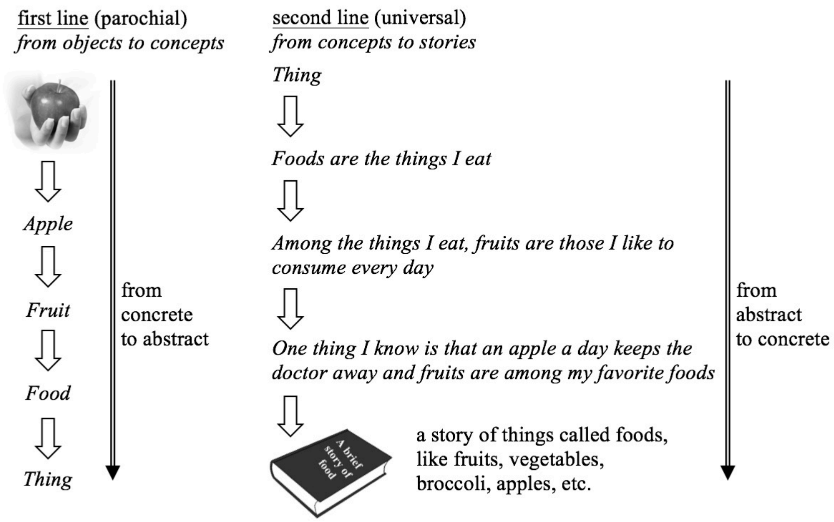

Figure 5 For human concepts there are two main lines connecting abstract to concrete. The first one goes from concrete to abstract: from objects to collections of objects having common features. The second one goes from abstract to concrete: from concepts to stories formed by the combination of many concepts.

So, there is a parochial line to go from the concrete to the abstract, linked to the historical way we have developed concepts (starting from our need to name the physical entities around us), by abstracting them from objects, and there is a second line (Aerts 2014), going from the abstract to the concrete, linked to how we humans have learned to combine concepts (in order to better think and communicate), creating more complex emergent meanings (see Figure

5). In this second line, the more abstract concepts are those that are expressible by single words, and concreteness increases when the number of conceptual combinations increases, so that the most concrete concepts are those typically described by large aggregates of meaning-connected (entangled) single-word concepts, which is what in our human realm we would generically indicate as *stories*, like those written in books, articles, webpages, etc. We don't mean here stories only in the reductive sense of novels, but in the more general sense of clusters of concepts that are combined together in an interesting way, so as to create a well-defined meaning. This second line is therefore very different from the previous one (in a sense, it is transversal to it), and we humans clearly use both lines at the same time, when communicating and creating new meanings. However, it is this second line that we believe is the truly fundamental and universal one, i.e., the one in which the human concepts have found their natural developmental niche.

The fact that in human language both lines exist and are mixed together can explain in part the fact that there are structural differences between our human conceptual realm and the micro-physical conceptual realm, in particular the fact that the latter will generally exhibit a higher level of symmetry and organization (another reason being that our human cultural evolution is a recent happening relative to the time scale of our universe). Now, consider a document containing a text, and assume that the text contains the word "horse." This means that the story in such document is a (deterministic) context specifying a state of the concept *Horse*, which according to the second line of concretization would be a very concrete state. Of course, this same document can also be considered to describe the state of concepts indicated by other words in the story, or even concepts whose words are not specifically mentioned but are nevertheless strongly meaning-connected to its content. It is worth emphasizing that this document, containing a story about *Horse*, is not necessarily associated with a physical horse that one can touch and ride (an instantiation of *Horse*, according to the first line of concretization). For instance, the text may refer to the drawing of a horse, which of course is not a living entity, or maybe the term "horse" is only used in a metaphorical way, like in the Italian saying "la superbia va a cavallo e torna a piedi" (pride rides a horse and walks back). However, since the document contains a whole story, the latter will behave in the conceptual realm in a way that is similar to how macro-physical objects also behave.

To explain what we mean, consider two objects, let us call them object-A and object-B. When we consider the conceptual combination *Object-A and object-B* (using the 'and' logical connective),[5] we are still able to put it in a correspondence with an object, and more precisely the object that is obtained by bringing together the two objects, now forming a single composite object (let us call it object-$A \wedge B$). On the other hand, when we consider the conceptual combination *Object-A or object-B* (using the 'or' logical connective), we are not able anymore to associate it with an object. But if we have two concepts, let us call them *Concept-A* and *Concept-B*, then not only *Concept-A and concept-B* is again a concept, but also *Concept-A or concept-B* is a concept. So, the conceptual realm is closed with respect to the conjunction and disjunction connectives, whereas the realm of objects is by definition only closed with respect to the conjunction connective (the conjunction of two objects is still an object, but the disjunction of two objects is not anymore an object).

What about stories, i.e., conceptual entities that are formed by large combinations of concepts that are connected through meaning? Of course, since a story is still a concept, and more precisely a concept that is obtained by consistently combining numerous other concepts, as described by the specific combination of words that are present in a document (like a book, a webpage, etc.) that makes the story manifest, the above must still hold: if we have two stories, let us call them *Story-A* and *Story-B*, then also *Story-A and story-B* and *Story-A or story-B* are to be considered stories. But the subtle point is in the distinction between the notion of story as a concept (i.e., a meaning entity) and the possibility for a story to be also manifest in concrete form in our spatial theater. Consider two actual books, let us call them book-A and book-B, with book-A containing the words of *Story-A*, and book-B containing the words of *Story-B*. What about the books associated with the two stories *Story-A and story-B* and *Story-A or story-B*? Let us call them book-$A \wedge B$ and book-$A \vee B$, respectively. The former can simply be

[5] To facilitate understanding, we will always denote concepts using italic type fonts and an uppercase first letter, to distinguish them from objects, which we will indicate using roman type fonts.

considered as the juxtaposition of book-A and book-B, which means that as soon as two books exist, each one telling a different story, then also the book containing the conjunction of their two stories can be considered to exist, and to correspond to the book obtained by placing the two books side by side. In other words, when looking at the shelves of a bookstore, with the different books placed in them side by side, we are actually contemplating stories that are conjunctions of other stories.

The situation is different when we consider the disjunction of two stories. In a bookstore, we will usually not find books of the form book-$A \vee B$. This not because it would be difficult to create an object of this kind, in our material world. Indeed, to do so, we only have to create a single page having the word "or" written on it, then consider the juxtaposition of book-A, such page, and book-B. But the probability to find an artifact of this kind in a bookstore is extremely low, and this because in our human culture it would not be considered to be the manifestation (the collapsed state) of a meaningful story, as is clear that for two arbitrary stories, *Story-A* and *Story-B*, the ambiguity introduced by the *Or* connective will be considered to be too artificial for *Story-A or story-B* to deserve to be engraved in a concrete document. To put it in a different way, in general the *Or* connective in *Story-A or story-B* will not provide a sufficiently strong meaning-connection for *Story-A or story-B* to be able to also appear in a *bona fide* book that humans can buy in bookstores. In other words, although in theory book-$A \vee B$, telling *Story-A or story-B*, can be easily physically created, it will only appear with a very small probability within the field of our human cultural activity. The above does not mean, however, that stories that are disjunctions of other stories will not appear in documents that are part of our human culture. This will be the case of all texts that, for narrative reasons, require to specifically introduce such an aspect of two storylines that are told one after the other, with a disjunction in between. A typical example would be that of a detective story, in which different scenarios are told as possible solutions of a crime. Note that as we consider smaller pieces of texts, disjunctions will appear much more frequently, like in sentences of the "coffee or tea" and "dead or alive" kind.

So, different from the disjunctions of stories, conjunctions of stories are in a much more obvious (concrete) way stories again, and this difference in behavior of stories in relation to the *And* and *Or* connectives indicates their special status as elements of greater concreteness of a conceptual realm. And in the same way as objects that are conjunction of other objects need more space to manifest in our spatial theater, stories that are conjunctions of other stories also need more "space" to manifest, i.e., more pages, more words, more memory on a computer, in case they would be electronic documents, etc. However, different from the ordinary objects, there is not yet for our human stories the equivalent of a well-structured spatial realm, and surely there are many different ways of defining the embryonic structure from which a more organized and symmetric environment might one day emerge.

As a paradigmatic example, consider that specific collection of human stories that we have called the World Wide Web. Its interlinked webpages can be understood as the possible spatiotemporal manifestations of a rather complex abstract entity of meaning (formed by the combination of multiple concepts), whose full description requires the use of the quantum formalism (or even more general quantum-like formalisms). This perspective was recently considered in some detail as a way to capture the full meaning content of collections of documental entities, and the name QWeb was proposed to denote such meaning entity, to distinguish it from the spatiotemporal Web of written pages (Aerts et al. 2018a). The QWeb, as a quantum-meaning entity, can be in different states: some of them will be more abstract, others more concrete, the most concrete ones being the stories associated with the different printable webpages. We can thus consider the entire collection of interlinked webpages as the equivalent of our three-dimensional Euclidean space, understood as a theater for those (classical) entities we call objects. In other words, we can consider the Web's collection of documents at a given moment of our human cultural history to be the equivalent (or rather, the embryonic version) of the possible spatial locations that micro and macro physical entities can occupy, be it in ephemeral or more permanent ways.

This means that we interpret the different stories associated with the different webpages as the equivalent of the spatial states to which the QWeb entity (or some of its sub-conceptual entities) can transition to, in given experimental contexts, like for instance the interrogative context where a human inserts the word "horse" in the Google search engine, to obtain, as a result, a story about *Horse*, among the different possible ones. Such a search experiment can be considered to be the equivalent of a quantum measurement, although of course the parallel is not complete, as is clear that search engines like Google still operate today in a deterministic way, whereas quantum measurements are genuinely indeterministic, as the decision processes operated by humans also probably are (see Section 9). But we can certainly consider in our parallel a future versions of search engines, also integrating in their functioning probabilistic processes (i.e., some level of randomness), and in any case even today a human is always presented with a collection of possible results, ordered according to their relevance, and s/he has thus to decide on which of the obtained list of links to click, introducing in this way an element of unpredictability in the process.

Before continuing with the discussion, let us stress again the double status of webpages: they have acquired the status of objects in our human world, as it is the case for all human artifacts, but they also describe complex conceptual combinations (what we have called stories) that correspond to the most concrete states of the QWeb conceptual entity. But not all human artifacts are necessarily associated with maximally concrete states of concepts, according the second line of concretization depicted in Figure 5. For instance, a piece of paper with the single word "horse" written on it, is an entity in a maximally concrete state according to the first line (it is an object), but not an entity in a maximally concrete state according to the second line (it is not a story).[6] Having said that, we immediately see that a concept like *Animal*, say in the state *The animal is a horse*, which as we discussed can be considered to be a fairly abstract state, entertains a strong meaning-connection with a number of webpages, for instance all those containing the word "horse," and

[6] In our Web analogy, we are assuming that humans are only motivated to create a webpage when it can convey a sufficiently articulated and complex meaning, and that a webpage containing, say, the single word "horse," will not be deemed to be sufficiently interesting to justify the effort (the energy to be spent) for its creation, in the same way that we do not find on the shelves of a bookstore volumes whose pages, except for the cover title, would be all empty. But of course, artifacts of this kind are not in principle impossible to create, and in fact are also created. For instance, in a stationery shop, one can find notebooks, which are volumes without printed words. But a stationery is a very different context from that of a library, or of a bookstore.

this means that the conceptual entity *Animal* is potentially present in all these webpages, i.e., in all these clusters of meanings that are stories about *Horse* and which can be selected in an experiment consisting in finding a good example of a horse story. But since a conceptual entity can only be in a state at once, for as long as a webpage is not selected, we cannot say it is actually present in space (and time), as for this it has to acquire, at a given moment, one of the states belonging to the Web spatial canvas of states.

We thus have here an interesting explanation of non-locality. First of all, as highlighted in many works even before the conceptuality interpretation was proposed, *non-locality means non-spatiality* (Aerts 1998, 1999). Our three-dimensional Euclidean space (or more generally our four-dimensional Minkowskian space, possibly also curved by gravity) should not be considered the overall theater of our physical reality, but 'a space' that emerged following the structuring of the macro-physical entities that grew out of the micro-ones. The conceptuality interpretation adds however an important piece of explanation, regarding how we should understand this notion of non-spatiality: *non-spatiality means abstractness*. More precisely, non-locality and non-spatiality would result from the fact that the micro-physical entities being conceptual entities, stories (complex combinations of concepts) can form out of them, with *coherence* (the structuring element for their formation) being nothing than the expression of a meaning-connection, exactly in the same way as, in the human conceptual realm, stories, and in particular webpages, originate and are structured through the meaning contained in individual and collective worldviews. And these meanings, connecting the more abstract concepts to the more concrete ones, explain why quantum conceptual entities are always available in acquiring spatial properties, by lending themselves to be detected by the physical apparatuses that belong to that semantic space (the Euclidean space) which is a theater for their stories.

Consider a story mentioning an *Animal* at different places in its narrative. Imagine that, at some moment, the *Animal* gets specified as being a *Horse*, i.e., the *Animal* concept in the story enters *The animal is a horse* state. Then, in no time, it will become a *Horse* everywhere else in the story, where it was referred to as *Animal*, which is precisely what happens in experiments when entities separated in space by large distances are observed to simultaneously change their states in a correlated way.

6 Objects as limit of concepts

It follows from the discussion above that what we usually call objects (classical entities having stable spatiotemporal properties) would be nothing but conceptual entities having reached the status of full-fledged stories, i.e., of sufficiently complex combinations of meaning-interconnected concepts. Again, we stress the importance of not confusing artifacts containing human stories (like printed webpages) with the fact that these human artifacts, as macroscopic material entities, are in turn story-like non-human conceptual entities. The notion of object, as used in classical physics, would then be only an idealization, as the object behavior would only depend on the conceptual/cognitive environment in which an entity is immersed. Consider the example of O'Connell mechanical resonator (a small 60 μm flap, large enough to be seen with the naked eyes) which they succeeded putting in a superposition of two classically mutually exclusive states, one "vibrating a little" and the other "vibrating a lot" (O'Connell 2010). As another example, consider the experiment performed by Gerlich et al., where organic molecules formed by up to 430 atoms, with maximum sizes of up to 60 angstrom, were successfully put in a superposition of states localized in regions of space separated by distances of orders of magnitude larger than the molecules' sizes (Gerlich et al. 2011). Experiments of this kind indicate that also big material entities, like chairs and tables, could in principle enter non-spatial states. Take a chair. If, at a fundamental level, it is also a story-conceptual entity, then it can be in different conceptual states. The most neutral one is simply the state expressing it existence, which we can describe by the conceptual combination *The chair is a chair*, or *The chair exists*. Other states of the chair-conceptual entity are easy to encounter in our human environment, like the state: *The chair is in the bedroom* or *The chair is in the livingroom*. These are eigenstates relative to the contexts where chairs are usually found. But in principle, and although this may well never be in our reach in experimental terms, one could also create interrogative contexts, like those considered by Gerlich et al. for the organic molecules, where a chair's state would be described for instance by the conceptual combination: *The chair is in the bedroom or in the livingroom*.

The enormous difficulty in obtaining in practice a state of this kind is due to the fact that a chair is a very complex object, i.e., a very complex story, formed by numerous sub-stories, and that to put an entity of this level of complexity in a state of superposition is about finding a way to decompose such story into what can be described as the disjunction of two different stories: one corresponding to the chair being in the spatial state *The chair is in the bedroom*, and the other one corresponding to that same chair being in the spatial state *The chair is in the livingroom*.[7] So, to obtain a state like *The chair is in the bedroom or in the livingroom*, for a macroscopic material entity like a chair, an experimental setting playing the role of a mind-like cognitive entity needs to be put in place, able to consistently decompose its meaning in a way that we would precisely describe as the disjunction of two different chair-stories (without destroying the chair-entity). Note that human minds can easily create such an interrogative context, when they express a lack of knowledge about where the chair actually is, and formulate such uncertainty-ambiguity situation using the "or" connective, i.e., producing a more abstract state.[8] This means that within the human conceptual realm, human minds can easily provide a context/interface that can interact with a chair-entity in a conceptual way, i.e., put it in a superposition state that they can subsequently collapse, when some

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[7] The conceptuality language is very fluid: a conceptual combination used to describe the state of a conceptual entity can also in turn, depending on the context considered, be interpreted as a composite entity of its own. Here the focus is on the entity *Chair*, so a combination like *The chair is in the bedroom* is to be interpreted as a specification of one of its possible states, but *The chair is in the bedroom*, as a combination of 6 different concepts, can also be interpreted as a multipartite conceptual entity, which in turn can also be in different states.

[8] To conveniently describe the conjunction as a superposition state, the lack of knowledge in question needs to be a deep one, such that one does not even know if the chair is either in the bedroom or in the living room, i.e., if the chair is or not in a spatial state. In other words (see the analysis of the double-slit and delayed choice experiments in Secs. 2, 3) the "or" needs to be understood in an non-exclusive way.

additional knowledge is acquired. This should not be misinterpreted, however, as human minds objectively collapsing the physical chair, as considered in 'consciousness causes collapse' interpretations like the von Neumann-Wigner. Again, we have not to confuse human concepts with the conceptuality of the physical entities, and human cognition with the cognitive behavior of the material entities (like the measuring apparatuses) that are sensitive to the meaning carried by the conceptual physical entities.

So, can we create a physical context able to put a chair in a superposition state, corresponding to two different locations,[9] and at the same time also provide an interface able to conceptually interact with the chair in such a superposition state, i.e., to understand the meaning it carries and possibly subsequently collapse it onto states having well-defined spatial properties, as we can do with microscopic and mesoscopic physical entities? As we said, our tentative answer is that this should in principle be possible, and the fact that so far we have idealized entities like chairs as objects, instead of conceptual entities, is because their conceptual nature can only manifest when a context of the double-slit kind is created for them. But what could be considered the equivalent of a detecting screen for an entity like a chair? We can observe that since our standard terrestrial environment is able to maintain macroscopic bodies constantly in space, then this same environment can be expected to be able of also producing the collapse – the objectification – of a macro-entity like a chair in a superposition state. But then, how can we bring an entire chair in a more abstract state, of spatial superposition? Why would it be so difficult to do so, in comparison to, say, a hydrogen atom? The answer is simple: for larger and larger entities, it becomes increasingly difficult to obtain an effective shielding from the unceasing random thermal bombardment to which they are subjected to, on the surface of our planet, and there is not only the external bombardment: also the internal environment of the chair needs to be taken into account.

To explain what we mean, we can reason as follows. To put the

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[9] In other words, a superposition that is experienced as such by all the material entities playing the role of minds with respect to the proto-language of which the chair would be part of, and not a superposition for the human minds experiencing a doubt regarding the location of the chair, and expressing it by means of the disjunction connective.

whole chair in a superposition of two different spatial locations, we have to be able to describe the chair-entity as a coherent whole. In mathematical terms, this can be translated into the possibility of factorizing the wave function in a way that the center of mass contribution separates from the contribution coming from the movements of the different constituents, relative to that center and to each other's. Indeed, it is not the part of the wave function describing the relative motion of the internal components that we want to put in a superposition state (as this part of the wave function describes the structure of the chair, which we want to preserve), but that describing its center of mass, which describes the potential localization in space of the chair. In the case of a hydrogen atom, it is straightforward to separate the wave function relative to the center of mass from that associated with the relative motion, obtaining in this way a description of the evolution of the center of mass as a free evolving wave function (see any manual of quantum mechanics). But with a macroscopic body things get much more complicated, as to be able to describe the chair's center of mass by means of a free evolving wave-packet, the evolution of the body's center of mass needs to decouple from all internal degrees of freedom, and this can reasonably be done only if the body is cooled down to extremely low temperatures. How low? Well, low enough to avoid any exchange of energy between the center of mass degree of freedom and the degrees of freedom associated with all the internal relative movements (Sun et al. 2001).

One may wonder why these exchanges of energy would be so problematic. It is of course easy to understand that the external bombardment of heat packets of energy can cause what is usually denoted as *loss of quantum coherence*, which within the conceptuality interpretation translates into *loss of meaning*. This loss of meaning is caused by the fact that when a physical system is forced to communicate with a noisy environment, this will consequently blur also the internal communications, with the result that the internal components will cease to behave as a coherent whole. But even if the external bombardment would not be thermal, but fully coherent, this would probably not solve the problem of the blurring of the internal communications of the chair-entity. Indeed, a chair is a very complex entity, made of innumerable parts, some of which are more cohesive than others. It is like an environment formed by different individuals, with different brains, so that even when they all receive the same input, like a spoken sentence (a concept in a given state), this will trigger a response that will differ depending on the individual involved. And of course, if numerous individuals are forced to chat together, all at the same time, without any coordination, producing each of them a different output, the overall result will be an unintelligible cacophony. This is what we can expect to happen in a photon-mediated communication happening at the level of the different pieces of matter that form the stuff the chair is made, like atoms, molecules, macromolecules, and other more or less separated coherent domains, because of the incessant processes of excitation and de-excitation.

The problem of this discordant and meaningless mixture of different communications can in principle be solved by silencing all the participants, taking away their energy by cooling down the chair-entity to extremely low temperatures, and of course do the same with its external environment. In these conditions of extremely cold external and internal environments, also a chair, at least in principle, could be brought into a non-spatial superposition state, by letting it interact with a macro equivalent of a double-slit context. Now, considering once more the parallel between a complex entity like a chair and the notion of story, we can observe that also in our human written stories there are parts of them that are more cohesive than others. Take the example of a novel: different chapters, which are like sub-stories, can be distinguished, and then there are the paragraphs, usually also containing more cohesive and self-contained "units of discourse," associated with given ideas (so that each paragraph can be considered to be a conceptual entity in its own, in the specific state described by the combinations of words in the paragraph). But going even further, and considering the more specific human line of concretization, we can also observe in human documents the presence of the "and" and "or" connectives, with the former being usually much more abundant than the latter. As we observed already, the connective "or" usually increases the level of abstraction, whereas the connective "and" would typically go in the direction of making the combination more concrete. Clearly, *Duck and mole* conveys a much more specific meaning than *Duck or mole*, as the "or" is more easily associated with a new possible emergent meaning, not reducible to those conveyed by *Duck* and *Mole* taken separately, and which in the long run might acquire a brand new term for its designation.[10]

This breaking of symmetry between the "and" and "or" in human documental entities, and the fact that, generally speaking, the "or" connective produces stronger connections in meaning than the "and" connective (compare for instance *Dead or alive* with *Dead and alive*, *Trick or treat* with *Trick and treat*, etc.), is indicative of the fact that different *domains of meaning* exist within texts, where the concepts belonging to these domains are much more submerged in each other's meaning, so that a clustering of documents in meaning structures of different sizes is inherent in the way a meaning type of interaction works at a fundamental level. And of course, the clustering process causes an objectification process, with the larger clusters usually attaining a stronger object status within the governing meaning type of interaction. And in a physical object like a chair, the same will happen, if we understand quantum coherence to be the equivalent of meaning in the case of micro-entities: there will be domains of coherence within a chair, separated from other *domains of coherence*, which in fact makes a chair, with good approximation, an entity formed by the conjunction of different parts with almost no meaning connection between them (no superposition), i.e., behaving almost as different objects. However, their conceptual nature can still be revealed, if an appropriate experimental context is put in place, like a context where the overall energy is lowered to a point where the *de Broglie wave length* associated to all these separated domains can overlap and start to intimately communicate [for a detailed discussion of the notion of de Broglie wave length, see Aerts (2014)]. Let us mention here *en passant* the difference between a dead piece of matter, like a chair, and a living piece of matter, like a platypus. One can say that the latter, different from the former, was able to construct, at room temperature, structures with nested domains of coherence (meaning) of all possible sizes, up to the size of the entire body of the living entity.

[10] The effects of the "and" and "or" conjunctions as regards making a combination more or less abstract is in fact much more articulated; see for instance the discussions in Aerts (2010b, 2014).

7 Entanglement

After what we discussed already in the previous sections, it becomes easier to explain how entanglement can be accounted for in a satisfying way in the conceptuality interpretation. Entanglement is among the better studied and experimentally verified quantum phenomena, and one that appears to defy our common (spatial) sense, which is the reason why Einstein famously described entanglement as a "spooky action at a distance." Indeed, the possibility of creating a condition of entanglement between two micro-entities appears not to depend on the spatial distance separating them or, to put it in more precise terms, appears not to depend on the spatial distance between the locations where the entangled entities can be detected with high probability. A characteristic of quantum entanglement (a direct consequence of the superposition principle) is that it is ubiquitous,[11] in the sense that quantum entities naturally entangle whenever they are allowed to interact and will typically remain entangled for as long as nothing intervenes to disentangle them (to decohere them). This ubiquitousness of entanglement mirrors the ubiquitousness of the *meaning-connections* that are unavoidably present in any conceptual realm. As soon as two conceptual entities are allowed to meet in a given cognitive context, a meaning-connection will exist between them, whose strength will of course depend on how much meaning the two entities can share and exchange.

Take the example of the two concepts *Animal* and *Acts*. These are two abstract concepts that are quite strongly meaning-connected in most contexts, as we all know from our experience of the world that animals are living beings and that living beings can do different types of actions, and that there are actions that certain animals will typically do that other animals will not do. This connection becomes perfectly evident when these two concepts are combined in a sentence like *The animal acts*. Almost all human minds will agree that such sentence possesses a full and perfectly understandable

[11] This explains why standard quantum mechanics cannot consistently describe separated physical systems (Aerts 1984); see also Sect. 3 of Aerts (2014).

meaning. To better understand the nature of this meaning-connection between *Animal* and *Acts*, when combined as *The animal acts*, we can consider two couples of exemplars for both concepts, like the following ones (Aerts and Sozzo 2011): (*Horse*, *Bear*) and (*Tiger*, *Cat*) for *Animal*, and let us denote these two couples A and A', respectively, then (*Growls*, *Whinnies*) and (*Snorts*, *Meows*), for *Acts*, and let us denote them B and B', respectively. One can then invite a certain number of individuals to participate in the following coincidence experiment. Considering the combination *The animal acts*, they are asked to select pairs of exemplars for these two concepts, as representative examples of their combination. If they choose from the couples A and B, their selection will be considered to be the outcome of a joint measurement denoted AB, and similarly for the other combinations, thus defining in total four joint measurements: AB, $A'B$, AB' and $A'B'$. The statistics of all these outcomes can then be analyzed in the same way physicists analyze data of Bell-test experiments, for instance using that version of Bell's inequality known as the Clauser, Horne, Shimony and Holt (CHSH) inequality (Clauser et al. 1969).[12] And the result is that the inequality will be violated with magnitudes similar to those of typical laboratory physics' situations with entangled spins or entangled photons (Aerts and Sozzo 2011, 2014).

So, the conceptual combination *The Animal Acts* describes what in physics is considered to be an entangled state. Such combination contains both a specification of the state of *Animal* and of the state of *Acts*, but also a specification of the "state of their connection." Indeed, if instead of *The animal acts* we would have used the more complex combination *An animal that has been doped acts in a strange way*, not only the specification of the states of *Animal* and *Acts* would be different, but also their meaning connection, in that

[12] The CHSH inequality is $|S| \leq 2$, with:

$$S \equiv E(A,B) - E(A,B') + E(A',B) + E(A',B')$$

where $E(A,B)$ denotes the expectation value for the joint measurement AB, given by:

$$E(A,B) = p(A_1,B_1) - p(A_1,B_2) - p(A_2,B_1) + p(A_2,B_2)$$

with $p(A_1,B_1)$ the probability for obtaining the pair of outcomes (A_1,B_1), i.e., (*Horse*, *Growls*), corresponding to the combination *The horse growls*, and similarly for the other probabilities and joint measurements.

context, would be different. This however is not how one would usually interpret an entangled state in quantum mechanics. Indeed, since genuine quantum states are only assumed to be described by pure states, and one cannot associate pure states to the different components of a composite entity when they are entangled, the usual conclusion is that when a composite entity is in an entangled state, its components cease to exist, in the same way as two water droplets also cease to exist when they are fused into a single larger droplet. This however is not fully consistent with the observation that entanglement preserves the structure of the composite entity. For instance, two entangled electrons, when disentangled, will still have the same mass and electric charge. In other words, quantum entities certainly do not completely disappear when entangled, as the conceptual combination *The animal acts*, interpreted as an entangled states, also indicates. So, do we have an incompatibility between the conceptuality interpretation and what the standard quantum formalism indicates? Surely not, though the conceptuality interpretation certainly pushes us towards a completion of the quantum formalism, to also allow the components of an entangled system to remain in well-defined states. This can be done by adopting the recently derived *extended Bloch representation* (EBR) of quantum mechanics (Aerts and Sassoli de Bianchi 2014a), where one can consistently represent the state of a bipartite composite entity as a triple of (real) vectors, with two of them specifying the individual states of the two components and the third one (of higher dimensionality) the state of their connection (Aerts and Sassoli de Bianchi 2016a, b). The reason why the extended Bloch representation can do so is that it is a completed version of the quantum formalism, where density operators also play a role as representatives of genuine states, so that one no longer needs to give up the general principle saying that a composite system exists, and therefore is in a well-defined state, if and only if its components also exist, and therefore are in well-defined states (see also Section 9, for the role played by the EBR in relation to the measurement problem).

As soon as we explain entanglement as a meaning-connection, the phenomenon is demystified. First of all, because it becomes clear that there are no communications through space that should be associated with the quantum correlations, as a meaning-connection between two concepts is an abstract element of reality, not manifesting at the level of our spatial theater. And it is also clear that although it is correct to describe an entangled system, like two entangled electrons, as a whole, because of the presence of the meaning-connection playing the role of a connective element, not for this one should think that the conceptual entities would have lost their identity in the combination (in a nutshell, entanglement, as an emergent phenomenon, is not "$1 + 1 \to 1$," but "$1 + 1 \to 3$"). And once one considers the role played by this connecting element, it becomes evident that when individual properties are created (instead of just discovered) in a coincidence measurement, also correlations will be created (instead of just discovered), precisely because of the presence of a non-spatial (more abstract) connection. In other words, it is because correlations are created in a joint measurement [called *correlations of the second kind* Aerts (1991); Aerts and Sassoli de Bianchi (2016b)], instead of just discovered, that Bell's inequalities can be violated, and the only way to create correlations out of a composite entity is to have the components to be connected prior to the measurement.

To help better understand what we mean by this, consider two traditional dice. If we roll them at the same time, we will obtain 36 possible and equiprobable pairs of upper face-outcomes. This is a situation where no correlations can be detected in the statistics of outcomes. However, if we connect the dice through a rigid rod, then only certain couples of upper faces can be obtained, when they are jointly rolled, and not others (see Figure 6).

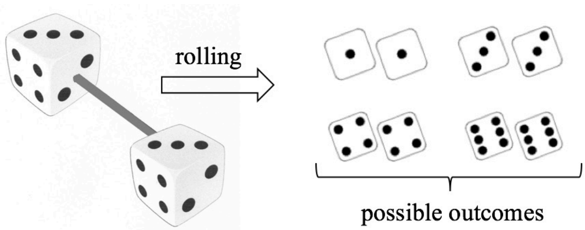

Figure 6 When two disconnected dice are jointly rolled, there are 36 equiprobable pairs of upper face-outcomes (no correlations). But if the two dice are connected through a rigid rod, when they are rolled only 4 pairs of upper face-outcomes can be obtained (correlations are created by the rolling experiment.

In this example, we can perfectly see the role played by the connecting element, here perfectly visible as a connection through space, and composite interconnected macro-systems of this kind can easily violate Bell's inequalities (Sassoli de Bianchi 2013). The connection through meaning plays exactly the same role of the rigid rod connecting the two dice through space. Of course, it will not work in such a stable way, when human minds select couples of exemplars representative of more abstract concepts, as fluctuations are also expected to be present. Remaining within the paradigm of the dice example, a more realistic description would be that of a rigid rod having a probability of also detaching and falling during the execution of the joint rolling process, so that correlations will not be always perfect, which is something that will typically lower the degree of violation of Bell's inequalities (Sassoli de Bianchi 2014).

To complete our discussion, let us also give the example of a conceptual situation that would be the equivalent of two micro-entities in a non-entangled (product) state, like two disconnected dice. Consider the conceptual combination *The animal is a cat whose favorite act is to meow*. Since such combination already actualizes a connection between *Cat* and *Meow*, the process of creating correlations during the joint measurement will be considerably reduced. In other words, we are here in a situation of *correlations of the first kind* (Aerts 1991; Aerts and Sassoli de Bianchi 2016b), which will be typically discovered instead of created during the experiment. More examples could be provided of human conceptual situations mimicking what happens in entangled micro-system, when interpreted as conceptual meaning-connected systems. A quite suggestive cognitive psychology experiment was for instance recently performed, where participants were asked to select pairs of wind directions they considered to be good representatives of *Two different wind directions*, with the data showing a violation of the CHSH inequality of magnitude close to that of experiments with entangled spins (Aerts et al. 2018b). A symmetrized version of the experiment was also considered, which received a complete quantum modeling in Hilbert space, using a singlet state to describe the meaning-connection and product measurements to describe the interrogative context where couples of actual wind directions were selected (Aerts et al. 2018c).

Let us use this last example of wind directions to make it even more explicit the parallel between the nature and behavior of conceptual and micro-physical entities. When we consider the conceptual combination *Two different wind directions*, none of the two winds concepts in it has a spatial direction. In the same way, considering two spin-1/2 quantum entities in a singlet (entangled) state, also in this situation the two spins have no spatial direction. These are only acquired when the two spin entities are forced by the measuring apparatus to acquire one, in the same way that participants to the cognitive experiment are forced to choose actual couples of wind directions. The way they do so depends on the accumulated human experience with winds blowing on the surface of our planet, and the meaning that was abstracted from these experiences. This will cause certain wind directions to be perceived as more different than others, thus favoring a process of creation of strong correlations during the selection of pairs of spatial directions that are judged be the best examples of *Two different wind directions*. This is exactly what also happens in coincidence experiments with two spin-1/2 entities in a singlet state, which is a state of zero spin where specific directions (eigenstates of the spin operators) have not yet been created. So, when the mind-like Stern-Gerlach apparatuses jointly select a spin direction, i.e., when they answer the question "What is the best example of two different spin directions?" they will produce an answer taking into account the meaning content carried by the composite conceptual spin entity, which can be described by the conceptual combination *The total spin value is zero* or, to express it in even more specific terms: *Spin orientations are always opposite when they are created along a same direction*.

8 Indistinguishability

In the previous section, we explained that entanglement, according to the conceptuality interpretation, is the expression of a meaning-connection between conceptual entities. Sometimes, entanglement is described as *quantum coherence*, where the term "coherence" is to be understood as a given, fixed relation between states, which is precisely what an entangled state is: a fixed relation between product states expressed by means of their superposition. This relation, or connection, is a meaning-connection existing before the entangled entities are subjected to possible interrogative contexts. So, realism is clearly not at stake when dealing with entanglement, as reality, as we explained already, would not be fully contained in the spatiotemporal theater and entangled quantum entities would be entities in more abstract states, available to acquire spatial properties (like locations and directions) only when submitted to suitable contexts, like the measurement ones. In other words, we have to distinguish what connects entities, and the effects that these connections produce in terms of correlations that can be created in the laboratories, which are processes where more concrete exemplars/instantiations of abstract concepts can be jointly actualized.

In this section, we want to address another of the quantum conundrums, *indistinguishability*, and explain why it can be convincingly elucidated by the conceptuality interpretation; this because concepts have a built-in notion of indistinguishability, which is apparently what we also use by default when we deal with large collections of concepts (Aerts 2009; Aerts et al. 2015). But before that, let us briefly recall what the notion of indistinguishability is about. Two entities – let us call them S_1 and S_2 – are said to be distinguishable if when we exchange their role this can have observable effects, at least in principle. Entities that are indistinguishable are said to be *identical*, and identical means that they possess exactly the same set of attributes, i.e., the same set of state-independent intrinsic properties, like for instance a same mass, charge and spin, as it is the case for all elementary micro-entities, for example electrons. Now, identical entities, although indistinguishable, are nevertheless *individuals*. This is precisely because they have attributes that can be measured and used to count how many of them are present in a composite system. For instance, the electric charge of a collection of electrons, if measured, will be Ne, with e the charge of a single electron and N an integer number indicating the number of identical electrons that are present in the collection. Hence, identical individuals are not necessarily a same individual, i.e., what renders two entities distinguishable appears not to be what also confers them their individuality.

Indistinguishability has profound consequences on the statistical behavior of identical entities, when considered collectively. Consider first the case where S_1 would be in some way distinguishable from S_2, and assume for simplicity that they can only be in two different states, let us call them ψ_1 and ψ_2. Then, the two entities, when considered as a composite system formed by two non-interacting sub-entities, can be in 4 different states [see Figure 7(a)]: one where both entities are in state ψ_1 one where both entities are in state ψ_2, one where S_1 is in state ψ_1 and S_2 is in state ψ_2, and finally one where S_1 is in state ψ_2 and S_2 is in state ψ_1. In the more general case where the number of distinguishable entities is n and the number of states they can be in is m, it is not difficult to see that the total number N of states of the composite system formed by n non-interacting sub-entities is: $N_{\mathrm{MB}} = m^n$, where the subscript "MB" stands for "Maxwell-Boltzmann," as this way of counting is characteristic for the classical *Maxwell-Boltzmann statistics*.

(a) Maxwell-Boltzmann

ψ_1	$S_1 S_2$		S_1	S_2
ψ_2		$S_1 S_2$	S_2	S_1

(b) Bose-Einstein

ψ_1	SS		S
ψ_2		SS	S

(c) Fermi-Dirac

ψ_1	S
ψ_2	S

Figure 7 The total number of states for two entities that can be in two different states, ψ_1 and ψ_2, when (a) they are distinguishable (spatial objects); (b) they are indistinguishable and can be in the same state (bosons); (c) they are indistinguishable but cannot be in the same state (fermions).

But consider now the situation where the two entities are indistinguishable. In this case, the situation where S_1 is in state ψ_1 and S_2 is in state ψ_2, and the situation where S_1 is in state ψ_2 and S_2 is in state ψ_1, cannot anymore be distinguished, hence they correspond to the same situation, which means that now we only have a total of 3 different states [see Figure 7(b)]. Again, a formula can be written for the general case:

$$N_{\mathrm{BE}} = \binom{n+m-1}{n} = \frac{(n+m-1)!}{n!\,(m-1)!}$$

where the subscript "BE" stands for "Bose-Einstein," as this way of counting is characteristic for the quantum *Bose-Einstein statistics*. For completeness, let us also describe a third situation, where not only the two entities are indistinguishable, but there is also the constraint that they cannot be jointly in the same state (Pauli's exclusion principle). Then only a single state remains for the composite system [see

Figure 7(c)], and for the general situation we have the formula:

$$N_{\mathrm{FD}} = \binom{m}{n} = \frac{m!}{n!\,(m-n)!}$$

where the subscript "FD" stands for "Fermi-Dirac," as this way of counting is characteristic for the quantum *Fermi-Dirac statistics*.

If the conceptuality interpretation correctly captures the nature of quantum entities, then quantum indistinguishability should appear also in the ambit of the human conceptual realm, at least to some extent, and produce non-classical statistics, not deducible from the MB way of counting states. Let us take the example of the abstract concept *Animal*. We can consider a certain number of these *Animal* concepts, say ten of them. A collection of this kind can be described by considering the two-concept combination: *Ten animals*. It is then clear that all the *Animal* concepts in the combination are completely identical and all exactly in the same state, i.e., all carrying exactly the same meaning, and that we are truly in the presence of a collection of entities, not of a single one. In other words, in the conceptual combination *Ten animals* the quantum indistinguishability becomes perfectly self-evident, so that the conceptuality interpretation offers a very simple and clear explanation of it. This would not possible for spatial objects, as is clear that two spatial objects are never indistinguishable, as they always occupy different locations in space, i.e., they are always in different spatial states. They can in principle all have the same intrinsic properties, but because of their spatio-temporal status they will always be distinguishable. So, the fact that *Ten animals* is a concept, and not an object, is crucial for it being able to carry the quantum feature of 'being many and at the same time being genuinely indistinguishable'.

Let us consider then two possible exemplars of *Animal*: *Cat* and *Dog*. These are to be considered as two possible states of *Animal*, i.e., the states expressing the meaning that *The animal is a cat* and *The animal is a dog*, respectively. We are thus in the situation where $m = 2$ and $n = 10$, so that $N_{\mathrm{BE}} = 11$. More specifically, the eleven states that the concept *Ten animals* can be in, when only the two exemplars *Cat* and *Dog* are considered, are:

$\psi_{10,0} =$ *Ten cats*
$\psi_{9,1} =$ *Nine cats and one dog*

$$\psi_{8,2} = \textit{Eight cats and two dogs}$$
$$\vdots \qquad \qquad \vdots$$
$$\psi_{2,8} = \textit{Two cats and eight dogs}$$
$$\psi_{1,9} = \textit{One cat and nine dogs}$$
$$\psi_{0,10} = \textit{Ten dogs}$$

If we assume that the *Cat* and *Dog* states can be actualized with the same probability and that there are no ways to distinguish between the individual cats, nor between the individual dogs, then the probabilities for obtaining all these states are the same, and given by $P_{\mathrm{BE}}(\psi_{10-i,i}) = \frac{1}{11}$, $i = 0, \ldots, 10$. On the other hand, in case there would be an underlying reality allowing to make further distinctions, then all these states would have a multiplicity. More precisely, the multiplicity of the state $\psi_{10-i,i}$ is $\frac{10!}{i!(10-i)!}$, which gives the MB probabilities ($i = 0, \ldots, 10$):

$$P_{\mathrm{MB}}(\psi_{10-i,i}) = \frac{10!}{i!\,(10-i)!\,2^{10}}$$

More specifically:

$$P_{\mathrm{MB}}(\psi_{10,0}) = P_{\mathrm{MB}}(\psi_{0,10}) = \frac{1}{1024},$$
$$P_{\mathrm{MB}}(\psi_{9,1}) = P_{\mathrm{MB}}(\psi_{1,9}) = \frac{5}{512},$$
$$P_{\mathrm{MB}}(\psi_{8,2}) = P_{\mathrm{MB}}(\psi_{2,8}) = \frac{45}{1025},$$
$$P_{\mathrm{MB}}(\psi_{7,3}) = P_{\mathrm{MB}}(\psi_{3,7}) = \frac{15}{128},$$
$$P_{\mathrm{MB}}(\psi_{6,4}) = P_{\mathrm{MB}}(\psi_{4,6}) = \frac{105}{512},$$
$$P_{\mathrm{MB}}(\psi_{5,5}) = \frac{63}{256}.$$

Can we find evidence for a deviation from the MB statistics to the BE one, due to the indistinguishability of the individual *Animal* concepts in the combination *Ten animals*? A possibility is to view the Web as a mind-like entity that can tell different stories, associated with all its searchable webpages. In this way, one can perform counts, using a search engine like Google, and use the obtained numbers as an estimate of the different probabilities [see Aerts et al. (2018a) for more details about this way of interrogating the Web]. When doing so, however, it is important to exclude the two extremal states $\psi_{10,0}$ = *Ten cats* and $\psi_{0,10}$ = *Ten dogs*, as these combinations will obtain counts that are two orders of magnitude greater than all the others, and this because the sentence "ten cats" (resp., "ten dogs") does not contain the "dog" (resp., "cat") word, and can thus easily combine with all possible other words. Furthermore, if we would use the more specific combination "ten cats and zero dogs" (resp., "ten dogs and zero cats"), we would obtain no counts, as we don't usually express things in this way in conventional human language. Thus, our Web interrogation will not provide correct data for the two states $\psi_{10,0}$ and $\psi_{0,10}$, which therefore must be dropped from the statistics. This means that we only start counting the number of pages containing the combinations "nine cats and one dog" or "one dog and nine cats." On August 20, 2017, Google gives: $N_{9,1} = 3090$. Doing the same for the combinations "eight cats two dogs" or "two dogs and eight cats," we obtain: $N_{8,2} = 4790$, and proceeding in the same way, we find: $N_{7,3} = 2580$, $N_{6,4} = 7390$, $N_{5,5} = 4460$, $N_{4,6} = 3310$, $N_{3,7} = 5020$, $N_{2,8} = 3710$, $N_{1,9} = 2980$. With

$$N = N_{9,1} + N_{8,2} + \cdots + N_{1,9} = 37330$$

we can thus calculate the weights ($i = 1, \dots, 9$):

$$P(\psi_{10-i,i}) = \frac{N_{10-i,i}}{N}$$

and interpret them as the experimental probabilities for the states $\psi_{10-i,i}$, $i = 1, \dots, 9$. These are:

$$P(\psi_{9,1}) = 0.083, P(\psi_{8,2}) = 0.128, P(\psi_{7,3}) = 0.069,$$
$$P(\psi_{6,4}) = 0.198, P(\psi_{5,5}) = 0.119, P(\psi_{4,6}) = 0.089,$$
$$P(\psi_{3,7}) = 0.134, P(\psi_{2,8}) = 0.099, P(\psi_{1,9}) = 0.080.$$

In Figure 8, we represent them together with the theoretical MB (P_{MB}) and BE P_{BE}) probabilities (after having renormalized them, following the cut off of the extremal states). Clearly, the data obtained from the counts are much more typical of a BE statistics, with some added fluctuations, than a classical MB one.[13]

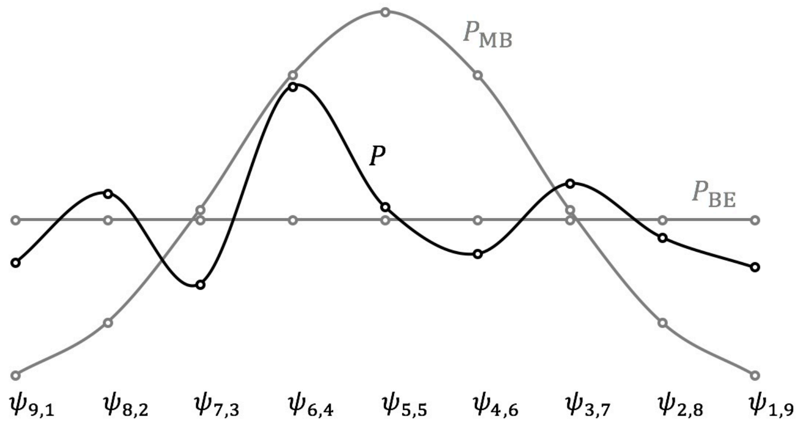

Figure 8 A comparison of the Maxwell-Boltzmann (P_{MB}) and BE (P_{BE}) probabilities with those obtained by performing Google's counts (on August 18, 2017) on the Web ($\boldsymbol{P}$), in the situation where the conceptual entitiy *Ten animals* is considered in relation to the two exemplar-states *Cat* and *Dog*. Note that the extremal states *Ten cats* and *Ten dogs* were not considered in the calculation.

Of course, Google's counts are far from being a precise estimate of the actual number of existing webpages containing specific combination of words, which means that the above is to be only considered as an illustrative example, more than a demonstrative one. More examples of Web counts can be found in Aerts (2009) and Aerts et al. (2015). But more importantly, in Aerts et al. (2015) experiments on human subjects were also performed. More precisely, 88 participants were given a list of concepts, like *Eleven animals*, *Nine humans*, *Eight expressions of emotion*, etc., in association with two of their possible exemplars, like *Cat* and *Dog* for *Animal*, *Man* and *Woman* for *Human*, *Laugh* and *Cry* for *Expression of emotion*, etc. More precisely, different numerical combinations of exemplars were each time presented to them, for each one of the concepts, asking them

[13] Note that these fluctuations are really such, in the sense that the deviations from the Bose-Einstein "flat line" will be generally different when different concepts are considered, say for instance *Horse* and *Cow* instead of *Cat* and *Dog*, to stay on animals. In other words, the observed deviations from the Bose-Einstein statistics cannot be generally attributed to a systematic classical multiplicity of the states.

to evaluate what are the most probable combinations, according to their preference. The obtained results show that the passage from the BE statistics (corresponding to a perception of strict indistinguishability of the concepts) to a classical MB one, depends on the concepts and exemplars considered in the experiment, in the sense that the easier it is to relate them to everyday life situations, and the more the obtained statistics will tend towards the MB one. On the other hand, the less the human imagination is influenced by real life situations (where MB statistics dominates) and can run free, the more the BE statistics will appear.

What about the Fermi-Dirac (FD) statistics, can we also find traces of it in the human conceptual realm? We can observe that the interfaces with which the human concepts interact, i.e., the memory structures sensitive to their meanings, are certainly organized according to *Pauli's exclusion principle*. Take the simple example of a computer, which will not allow one to make a copy of a file and name it in the same way, if memorized in the same folder. So, we can have identical copies of a same concept, but these identical copies must be in different states within the memory (in different folders in the computer). But we also know that entities formed by ordinary (baryonic) matter, which according to the conceptuality interpretation are the cognitive/memory-like entities interfacing with the bosonic messengers, are made of elementary fermions. So, one would expect to be also able to identify the equivalent of these fermionic elementary entities within our human conceptual realm. Consider for instance the well-known distinction between *count nouns* and *mass nouns* (also called *non-count nouns*). The count nouns are those that can be combined with a numeral (and therefore also accept the plural form). They give rise to combinations like *Ten Animals*, which as we discussed expresses a reality of ten identical entities all in the same state, typical of bosonic matter in so-called Bose-Einstein condensates. On the other hand, the mass nouns are those that have the property of not (meaningfully) combining with a numeral, without additional specifications. This means that we cannot have many identical non-count noun-concepts all in the same state. Take the example of the concept *Courage*, whose associated word has no plural form. The combination *Two courage* is clearly meaningless, which means that within the human language *Courage* is not a boson-like conceptual entity, as we cannot put a given number of them all in the same state. We are however allowed to write combinations like *Courage, courage, courage*, as we do when we repeat a word as a rhetorical device.[14] But then there will be an order, which means that the *Courage* conceptual entities in the combination will be in different states, which is the reason why the more they are in the combination, the greater will be the space required to write them on a page in the form of words.

To push this parallel a bit further, consider also the combination *Man of courage*. Even if it contains the non-countable concept *Courage*, it can now be meaningfully combined with a numeral, for instance in: *Ten men of courage*. This means that by combining a non-countable concept with other concepts, an emergent boson-like behavior can be obtained. This is similar to the well-known fact that fermions, when they aggregate, can behave as bosons, like in the typical example of the α-particles (Helium nuclei). Note that fermions can become bosons only when they are bond by some kind of interaction, which as we know is in turn mediated by bosons. This means that, strictly speaking, fermions alone cannot form a boson: we cannot construct bosons without bosons. In the above combination, *Man* is a boson-like (countable) concept, *Of* and *Courage* are not. So, we could say here that the two fermion-like concepts *Of* and *Courage* interact through the boson-like concept *Man*, producing the combination *Man of courage*, whose behavior is boson-like. All this is of course for the time being purely heuristic, as we cannot expect to find within the human language conceptual realm the same level of organization of the microphysical realm (nor by the way we should expect that the former will necessarily evolve, in a far distant future, towards a same type of organization of the latter). In that respect, consider that the fermionic/bosonic duality of the micro-entities is intimately related to the rotational properties of the fractionary/integer spins they carry, according to the well-known *spin-statistics theorem*. However, quoting from Aerts (2009): "[…] although we can express the requirement of identity in general terms, the situation of human concepts and their interface of memory structures has not evolved sufficiently to contain a structure where rotational invariance may be expressed in general terms. This is also

[14] This is called an epizeuxis (or palilogia), and is typically used for vehemence, or emphasis.

the reason that no equivalent of spin exists on this level." This does not mean that internal structures playing the same role in human concepts as spin and rotational invariance could not be identified, but this is a matter of future investigations.

To conclude this section about indistinguishability, consider also the concept *Animals*, i.e., *Animal* in the plural form, but not in a specific combination with a numeral. It clearly describes an ensemble of *Animal* conceptual entities all exactly in the same state, but whose number is perfectly undetermined. If we write *Animals* in an unpacked form, it can be understood as the infinite combination: *One animal or two animals or three animals or four animals, etc.*, which in the Hilbert space mathematical language one would write as a coherent superposition of the states *One animal*, *Two animals*, *Three animals*, etc., corresponding to the different possible numbers of *Animal* conceptual entities in their ground state. If you think of the harmonic oscillator, this would be like a state $|\phi\rangle$ which is an infinite superposition of number-operator ($N = a^\dagger a$) eigenstates: $|\phi\rangle = \sum_{n=1}^{\infty} e^{in\phi}|n\rangle$, i.e., a state where, according to the *number-phase uncertainty relation*, the indetermination on the number of entities would be maximal, whereas the indetermination on their phases would be minimal, so much so that a description as a classical wave phenomenon would be possible. This is not the case for fermionic (non-countable) entities, for which, as is well-known, a classical undulatory approximation has no validity (Lévy-Leblond and Balibar 1997).

9 Measurement problem

In the previous sections, we have considered different quantum phenomena and explained how they can be understood in the light of the conceptuality interpretation. By doing so, we have described the measuring apparatuses as memory structures sensitive to the meaning carried by the measured quantum conceptual entities, so that measurements would be like interrogative contexts during which a conceptual entity, usually prepared in an abstract (superposition) state, is forced to acquire a more specific state, corresponding to one of the possible answers that the experimental setting permit to be selected (similarly to when we have to fill a multiple choice form having predetermined answers to select). Of course, the fact that a measurement is like an interrogative process is a metaphor which can be used independently of the conceptuality interpretation. Indeed, a scientist, by means of a measurement, certainly interrogates the system subjected to it, and the outcome is the answer it receives. But this is a description only at the human cognitive level, which is necessarily always present in a scientific experiment, as is clear that science is a human activity. The conceptuality interpretation, however, adds a new cognitive layer: that of the meaning driven interaction between the measured entity and the measuring apparatus. So, the following question arises: Can human decision processes shed a light into what happens behind the scenes of a quantum measurement process and provide an additional argument in favor of the conceptuality interpretation?

To answer the above question, we have first to identify what are the important elements characterizing an interrogative process, when a cognitive entity is asked (or forced) to provide an answer when confronted with a given situation (that we can represent as a conceptual entity in a given state), selecting it from a number of predetermined possibilities. For this, we can ask what we intuitively feel when we are confronted with interrogative/decisional contexts of this kind. What we certainly can all recognize is that there will be a first phase during which we mentally immerse the situation in question into the context of the set of possible answers we have been given. If the situation is initially described by a state $D = |\psi\rangle\langle\psi|$ (which we write here as a projection operator), we can understand this first phase as a deterministic preparation process during which we bring the meaning of the situation as close as possible to the meaning of the different possible answers, which of course can also be described as final states of the conceptual entity which is the object of the interrogation. Assuming that there are N possible answers, let us call $D_i = |\psi\rangle_i\langle\psi_i|$, $i = 1, \dots, N$, these possible outcome states. So, there is a first immersive process during which the initial state D will transition to a new state D_e, expressing this more specific meaning-connection with the different possible outcomes/answers D_i. Since only one of them can be selected (they are mutually excluding answers), this

$D \rightarrow D_e$ immersive process creates a temporary state of unstable equilibrium (whence the index "e") between the competing tensions resulting from the different meaning-connections between D_e and the D_i. Therefore, a second (usually indeterministic) phase will occur, which we can also subjectively perceive. It is the phase during which the mental tensional-equilibrium that was built is all of a sudden disturbed, in a way that cannot usually be predicted in advance, with the disturbance causing an irreversible process during which the conceptual state D_e is drawn towards one of the possible answers D_i. This is really like a (weighted) symmetry breaking process, reducing the previously competing tensions and so allowing the cognitive entity to actualize an answer.

Note that the above two-phase cognitive process is a general description that can account also for situations where the answer is known in advance. In this case, the tensional equilibrium that is built will be a trivial one, in the sense that the meaning-connection with one of the outcomes will always prevail and produce the predetermined outcome without fail. But of course, in the general situations the interrogated person will not have yet formed a strong opinion regarding which answer is to be selected, so that all answers can truly play a competing role in the creation of the tensional equilibrium, and will therefore have a non-zero probability to be selected. It is important to say that what we are describing here is really a model of the mind's processes and not a model of the brain's processes, and that of course mind and brain processes need not to be the same.[15] But since the conceptuality interpretation assumes that the measuring apparatuses behave like cognitive entities, and the measuring apparatuses are precisely what physicists use to actualize an outcome, the following question arises: Can we also describe a quantum measurement process as a two-phase cognitive-like process where the initial state of the measured entity is first brought into a state of tensional equilibrium, which is subsequently broken in a way that the process exactly obeys the predictions of the Born rule? The answer is affirmative and the description in question is contained in the so-called *general tension-reduction* (GTR)

[15] For example, the modeling of the activity of Broca's area is very different from the modeling of how human language is used, although of course there will be correlates.

model (Aerts and Sassoli de Bianchi 2015a, b, 2016c), which in the special case where the state space is Hilbertian and the measurements are uniform reduces to the *extended Bloch representation* (EBR) that we mentioned already in Section 7 (Aerts and Sassoli de Bianchi 2014a, 2016b, 2017a).

More precisely, there is a way to reformulate the standard quantum formalism by using a generalization and extension of the historical three-dimensional Bloch sphere model, which contains an exact description of the above two-stage process. In other words, the quantum formalism naturally generalizes and extends into a representation which is compatible with a general description of a measurement as a cognitive-like interrogative process. When we say that it generalizes the Bloch sphere model, it is because it applies to quantum systems of any dimension N, in fact also of infinite dimension (Aerts and Sassoli de Bianchi 2019), and when we say it extends the Bloch sphere model, it is because it allows for a description, in the same representation, of the (hidden) measurement-interactions that are responsible for the breaking of the tensional equilibrium. It is of course not the purpose of the present work to enter into all the mathematical details of the GTR-model or the EBR of quantum mechanics. But let us provide some additional information about how the latter works. By introducing a representation for the generators of $SU(N)$, the special unitary group of degree N, it becomes possible to associate real (N^2-1)-dimensional unit vectors to the initial state D and the final states D_i\$, which we will denote $\boldsymbol{r}$ and $\boldsymbol{r}_i$, $i=1,\dots,N$, respectively. These are vectors living at the surface of a convex region of states that is inscribed in a (N^2-1)-dimensional unit sphere $B_1(\mathbb{R}^{N^2-1})$, which coincides with the latter only in the two-outcome ($N=2$) case [thanks to the isomorphism between $SU(2)$ and $SO(3)$]. Now, one can show that the N vectors $\boldsymbol{r}_i$ are the vertex vectors of a $(N-1)$-dimensional simplex $\Delta_{\mathrm{N-1}}$, inscribed both in the convex region of states and in $B_1(\mathbb{R}^{N^2-1})$.

The first phase of the measurement then corresponds to an immersion of the state vector $\boldsymbol{r}$ inside the sphere, along a path that is orthogonal to $\Delta_{\mathrm{N-1}}$, reaching in this way an equilibrium point $\boldsymbol{r}_e\in\Delta_{\mathrm{N-1}}$. This is the mathematical counterpart of the stage we previously described as the cognitive activity bringing the conceptual entity in full contact with the "potentiality region" generated by the N mutually excluding answers. From a mathematical viewpoint, this causes the initial projection operator D, associated with $\boldsymbol{r}$, to gradually decohere and transform into a fully reduced density operator

$$D_e = \sum_{i=1}^{N} P_B(\psi \to \psi_i) D_i$$

associated with the (non-unit) on-simplex vector $\boldsymbol{r}_e$, where the positive numbers

$$P_{\mathrm{B}}(\psi \to \psi_i) = |\langle \psi_i | \psi \rangle|^2$$

are the Born probabilities. And this means that in the EBR also the density operators play a role as representative of *genuine states* (as we mentioned already in Section 7, in relation to the description of entangled sub-systems), describing the (non-unitary) evolution of the entity during the measurement itself. At this point, we can consider the "tension lines" going from the on-simplex state $\boldsymbol{r}_e$ to the N outcome states $\boldsymbol{r}_i$, partitioning $\Delta_{\mathrm{N}-1}$ into N convex subregions A_i, formalizing the unstable tensional equilibrium we previously described. We can imagine these N regions to be filled with an abstract elastic and disintegrable substance, so that when one of the regions – say region A_i – starts disintegrating in a given internal point (this is the disturbance we previously described, due to the unavoidable fluctuations that are present in a measurement context), the disintegrative process will propagate within it, so that its $N-1$ anchor points will detach, with the consequence that the equilibrium state $\boldsymbol{r}_e$ (we can imagine it as an abstract point particle attached to the elastic substance) will be brought towards the remaning vertex vector, here $\boldsymbol{r}_i$, thus producing the measurement outcome (see Figure 9, for the $N=3$ case). It then follows from the geometric properties of the structures involved that if we calculate the probability that the disintegration point happens in sub-region A_i, which is simply given by the ratio $\mu(A_i)/\mu(\Delta_{\mathrm{N}-1})$ between the $(N-1)$-dimensional volume (or Lebesgue measure) of sub-region A_i and that of the full simplex $\Delta_{\mathrm{N}-1}$, that such ratio is exactly given by the probabilities $P_{\mathrm{B}}(\psi \to \psi_i) = |\langle \psi_i | \psi \rangle|^2$, i.e., by the quantum mechanical Born rule (Aerts and Sassoli de Bianchi 2014a, 2015a).

Let us mention that the process we just described, and its mathematical modeling, also generalizes to the situation of degenerate measurements (see the above references), when the *tension-reduction process* does not result in a full resolution of the conflict between all the competing answers, so that the state is brought into a state of sub-equilibrium, between a reduced set of possibilities, described by a lower-dimensional sub-simplex of Δ_{N-1}.

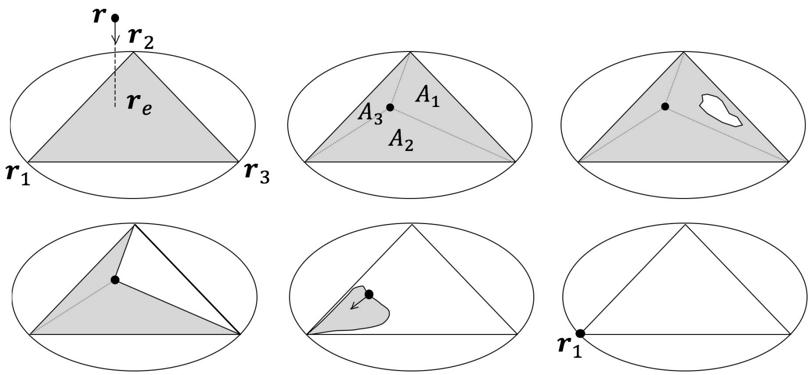

Figure 9 The unfolding of a measurement as a tension-reduction process, here with three possible (non-degenerate) outcomes: $\boldsymbol{r}_1, \boldsymbol{r}_2$ and $\boldsymbol{r}_3$. The abstract point particle representative of the initial state is positioned in $\boldsymbol{r}$, at the surface of the eight-dimensional sphere $B_1(\mathbb{R}^8)$ (which of course cannot be drawn). It then orthogonally "falls" onto the triangular elastic substance Δ_2 (an equilateral triangle) generated by the three outcomes, reaching the point $\boldsymbol{r}_e$ and so defining three convex sub-regions: A_1, A_2 and A_3. The substance of Δ_2 then starts disintegrating at some unpredictable point, here inside A_1, so that A_1 fully disintegrates and detaches from its two anchor points, thus drawing the point particle to its final location, here $\boldsymbol{r}_1$.

To conclude this section about quantum measurements, let us also consider what could be a possible objection regarding our parallel between measurements in physics laboratories and cognitive processes where a mind-like entity selects one among a set of possible answers, according to the information stored in its memory. As we know, when we answer a question, the *way* we do so can vary every time, depending on the mental state we are at that moment. Also, the way of choosing an answer of a person will generally differ from the way of choosing of another person. On the other hand, a measuring apparatus always chooses in the same way, which is the way described by the Born rule. In other words, each person should be associated with quantum-like probabilities which will generally differ from those predicted by the Born rule. This is of course correct, and as we mentioned already, we should not think of human culture, and the cognitive processes associated with it, as a reality domain that would have reached the level of symmetry and of organization of the micro-physical domain.

But to be truthful, we don't really know if the measuring apparatuses always choose according to the Born rule. All we know is that the Born rule emerges from the statistics constructed from numerous outcomes. We thus cannot exclude that at each run j of a measurement the apparatus would select an outcome according to probabilities $P^{(j)}(\psi \to \psi_i)$ which would generally differ from the Born probabilities $P_{\mathrm{B}}(\psi \to \psi_i)$. This would mean that an apparatus not only actualizes an outcome from a set of potential ones, but also, at a deeper level, actualizes a way of choosing an outcome from a (typically infinite) set of potential ways of choosing. Of course, for this to be consistent with the results we usually observe in the labs, the average

$$\langle P(\psi \to \psi_i)\rangle = \frac{1}{n}\sum_{j=1}^{n} P^{(j)}(\psi \to \psi_i)$$

should tend to the Born probability $P_{\mathrm{B}}(\psi \to \psi_i)$, as $n \to \infty$, for all $i = 1, \dots, N$. This kind of average, called a *universal average*, can be studied in the GTR-model by considering abstract non-uniform substances disintegrating in all possible ways, thus giving rise to all possible sets of probabilities for the different outcomes. These different non-uniform substances would describe the different "mental states" of the apparatus at each run of the measurement, and the remarkable result is that one can show that a universal measurement (when the state space is Hilbertian), exactly corresponds to a uniform measurement described by the quantum mechanical Born rule (Aerts and Sassoli de Bianchi 2014a, 2015b, 2017a).[16]

[16] See also Aerts and Sassoli de Bianchi (2014b), for a discussion of the notion of universal average in relation to Bertrand's paradox.

10 Relativity

To continue our exploration of the fertility of the conceptuality interpretation in providing new ways of explaining fundamental physical phenomena, we will now address *relativity theory*. Indeed, not only the quantum phenomena, but also the relativistic ones, do challenge our classical prejudices and, as we are now going to explain, also for them the conceptuality interpretation can help us shed some light on their possible origin. In doing so, we will limit ourselves to consider the phenomenon of *time dilation*. Also, we will limit our discussion to non-quantum relativistic entities (classical bodies) and will just provide at the end some clues about how to extend the reasoning to the quantum domain as well. But to begin with, let us observe that although the term "relativity" has been historically attached to Einstein, it refers in fact to a principle (the *relativity principle*) that is much more ancient, as it was already described by Galileo Galilei in his famous example of the ship advancing at uniform speed, with people locked in the cabin beneath the deck not able to determine whether the ship was moving or just standing still (Galilei 1632). In fact, one also finds descriptions of this principle as early as the first century B.C., i.e., 1700 years before Galileo, in China, in *The Apocryphal Treatise on the Shang Shu Section of the Historical Classic: Investigation of the Mysterious Brightnesses* (*Shang Shu Wei Kao Ling Yao*), where one can read: "Although people don't know it, the earth is constantly moving, just as someone sitting in a large boat with the cabin window closed is unaware that the boat is moving."

A possible synthetic statement of the relativistic principle is as follows: "Equivalent viewpoints exist on the physical world." When the principle is formalized by using the notion of *reference frame*, it then becomes (Lévy-Leblond 1977): "Equivalent frames of reference (space-time coordinate systems) exist for the physical laws, i.e., such that the physical laws have exactly the same form in all of them." This does not mean, however, that the different physical quantities will have the same values in the different equivalent reference frames: it means that they will obey exactly the same relations, so that phenomena will be perceived in the same way when experienced from these different but equivalent reference frames.[17] The simplest examples of equivalent frames of reference are those that are translated or rotated with respect to each other, but Galileo, and before him the ancient Chinese sages, identified a more interesting non-trivial class of equivalent reference frames: those moving with respect to each other at constant speed, called *inertial frames*. The remarkable consequence of inertial frames that are equivalent frames is that an object moving at constant speed, from the viewpoint of the laws of physics, must be described in exactly the same way as an object at rest, i.e., as an entity on which the resultant force acting on it is zero. The *first law of Newton*, or *principle of inertia*, then immediately follows: an object in motion at constant speed, like an object at rest, will forever remain in such state of motion, if not acted upon by some additional force.

A much more remarkable consequence follows from the observation that there are wave phenomena (like the electromagnetic ones) that appear to propagate through the very "substance of space," once called the ether. Indeed, if this would be the case, i.e., if space would be substantial and waves could propagate through its medium, then some physical effects (like interference effects) should manifest differently in different inertial frames, thus contradicting the very relativistic principle. But if the principle is true, as it appears to be, these differences should not be observed, and in fact have not so far been observed, for instance in the historical Michelson-Morley experiment and in those that followed, which showed instead that the speed of propagation in space of the electromagnetic fields is always the same, for all inertial frames and in all directions. This means that space, understood as an encompassing substantial theater for reality, becomes a problematic notion and that what we call space is essentially a relational construct, so that each physical entity, with its unique perspective, would actually inhabit 'a

[17] Of course, not all reference frames are equivalent. For example, when we are on a carousel rotating at a given speed, we will experience phenomena that would be absent if the carousel would be at rest, like the *centrifugal pseudo forces*. The interesting content of the principle of relativity is therefore that among the countless possible reference frames, some non-trivial ones exist that are perfectly equivalent.

different space'. And this means that, as it will become clearer in the following, we do not see objects moving in space because they would actually move in an objective spatial theater, but because we confer them a movement in order to keep them inside our personal spatial representation. Now, as is well-known, when the relativistic principle is applied in conjunction with some very general and natural hypothesis about space and time, the Lorentz transformations are obtained as the only possible transformations connecting the different equivalent inertial frames (Lévy-Leblond 1976). Remarkably, these transformations do not affect only the spatial coordinates, but also the temporal ones, and the consequence is that objects, when they move with respect to a given reference frame, they are shorter in comparison to when they are at rest (*length contraction*), and also, objects called clocks, when they move also run more slowly in comparison to clocks that are at rest (*time dilation*). This means that what relativity is telling us is that the spatial constructs associated with the different physical entities cannot be just spatial, but have to be genuinely spatiotemporal.

To highlight this fact, consider the following thought experiment [see Aerts (1999) for a more extensive discussion]. Imagine that you are at the *Vrije Universiteit Brussel* (VUB), in Belgium (usually referred to as the *Free University of Brussels*, in English-speaking contexts), and that it is September 29, 2017, say 3 pm.[18] We can call this your personal present moment t_0. When you are at VUB, at time t_0, since you are having a direct experience with the university, you can affirm with certainty that VUB is real for you, i.e., that VUB is an existing element of your present personal material reality. But what about the reality of, say, the *Università della Svizzera italiana* (USI), in Switzerland (usually referred to as the *University of Lugano*, in English-speaking contexts)? Since at time t_0 you are at the VUB, and you are not having an experience with the USI, can you nevertheless affirm that the USI is also an element of your present personal reality, at time t_0?

[18] On September 29--30, 2017, the *Centre Leo Apostel for Interdisciplinary Studies* (CLEA), Belgium, has organized the international symposium "Worlds of Entanglement," during which one of the authors presented the guidelines of the conceptuality interpretation to an heterogeneous audience, formed not only by physicists, but also mathematicians, social scientists, biologists, artists, philosophers, economists, and others. The present article is an extended version of the content of that presentation.

The answer is positive, and the reason for this is that, following EPR's reality criterion,[19] we know that reality is a construction about the possible: if, in your past, you would have decided to travel to Lugano, Switzerland, then with certainty you would have had a direct experience with the USI at the present time t_0, and considering the certainty of such a prediction, you can say that also the USI is an element of your personal reality, at time t_0. Consider now the VUB at subsequent time $t_1 > t_0$, where t_1 is September 30, 2017, 3 pm, i.e., one day in your future with respect to your present time t_0. Is the VUB at time t_1 also an element of your reality? If we rely only on our parochial conception of space and time, we would respond negatively, but this would be a wrong answer considering what we know about the relativistic effects, and more specifically the effect of time dilation: the slowdown of the ticking rate of moving clocks, when compared to those that remain at rest.

Indeed, if in your past, say on September 28, 2017, 3 pm, you would have used a space ship to travel at speed $v = \sqrt{3/4}\,c$ (where c is the speed of light in vacuum) to any destination, then back again along the same route, because of the relativistic time dilation effect you could have been back at VUB exactly when your smartphone would indicate September 29, 2017, 3 pm, whereas the smartphones of all other people at VUB would indicate September 30, 2017, 3 pm. So, if you take seriously EPR's reality criterion, you must conclude that the VUB, one day in its future, is also an element of your present personal reality. Now, since the present discussion is aimed at an interdisciplinary audience, we think it can be useful to also briefly explain how time dilation is calculated in relativity theory. So, there are two versions here of the same individual, one remaining at rest at VUB,[20] who we will call entity A, and the other

[19] In a famous article written in 1935, Einstein, Podolsky and Rosen (EPR) recognized that our construction of reality is based on our predictions about it. The original wording of their criterion is (Einstein et al. 1935): "If, without in any way disturbing a system, we can predict with certainty [...] the value of a physical quantity, then there exist an element of physical reality corresponding to this physical quantity." For a discussion of the criterion, see Sassoli de Bianchi (2011) and the references cited therein.

[20] VUB being on the surface of planet Earth, strictly speaking it cannot be associated with an inertial frame, but for simplicity we will neglect the planet's non-uniform motion in our reasoning.

performing the round-trip journey, who we will call entity B (see Figure 10). If we denote T_B the time-period of the clock carried by B during her/his trip, as measured by A, using an identical clock remaining at VUB, the time period of which is τ_A,[21] s/he will observe a time dilation effect, i.e., that T_B is greater than τ_A. More specifically, if v is the speed of B (when moving away or approaching A), then we have $T_B = \gamma\tau_A$, where $\gamma = 1/\sqrt{1-\frac{v^2}{c^2}}$ is the so-called *Lorentz gamma factor*, which is equal to 2 for the above value of the speed v. Hence, we have that $T_B = 2\tau_A$, i.e., that the clock traveling with B appears to A to run twice as slow than the clock that remained at VUB.

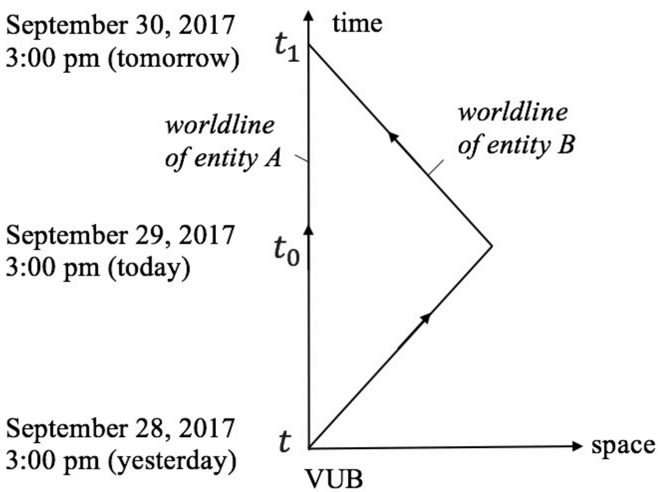

Figure 10 The two worldlines of the entities A and B, in the spacetime construction associated with the former. Entity A is spatially at rest, thus only moves along her time axis, whereas entity B goes on a round-trip journey, allowing her to meet again with entity A, in her – one day after – future.

Let us now assume that A measures n_A cycles of her/his clock for

[21] Note that we are using a different notation for the two time periods τ_A and T_B. This because the former is a so-called *proper time*, i.e., a time measured by a clock which remains at rest with respect to A, whereas the latter is a *coordinate time*, i.e., a time measured by a clock which is not at rest with respect to B.

the entire duration of the trip of B.[22] Since $T_B = \gamma\tau_A$, the number of cycles n_B of the clock of B will be obtained by solving the equation: $n_A\tau_A = n_B T_B = n_B\gamma\tau_A$, which gives $n_B = n_A/\gamma$, and for our value of the speed v we have: $n_B = n_A/2$. In other words, the traveling entity B uses half the time-cycles of the non-traveling entity A. Now, to determine the time $t < t_0$ (where t_0 corresponds to September 29, 2017, 3 pm) at which B would have needed to start her/his space travel at speed $v = \sqrt{3/4}\,c$, in order to be back at the same place, at VUB, at time t_1 (corresponding to September 30, 2017, 3 pm), with her/his clock indicating September 29, 2017, 3 pm, we can reason as follows. By definition, $n_A = (t_1 - t)/\tau_A$, and let us also denote n'_A the number of cycles corresponding to a one day (24 hours) period: $n'_A = (t_1 - t_0)/\tau_A$. We want that $n_B = n_A - n'_A$, i.e., we want the clock of B to use 24 hours less than the clock of A. Since $n_B = n_A/\gamma$ we obtain $n_A = \frac{\gamma}{\gamma-1} n'_A$, so that for $\gamma = 2$ we have $n_A = 2n'_A$. In other words, B has to start her/his trip two days before September 30, 2017, 3 pm, that is, on September 28, 2017, 3 pm (see Figure 10).

Coming back to our discussion, being our personal present reality defined in a counterfactual way, via the EPR criterion, we have to conclude, as a consequence of the relativistic *generalized parallax effects*, that our personal present also contains a part of our personal future. However, this not in the sense that all of our future would be given, as if the universe would be an unchanging block. Indeed, if it is true that in a given reference frame we can always attach time and space coordinates to the different events, this doesn't mean that the processes of change that have created them are also happening in space and time. Indeed, these processes typically originate from a non-spatiotemporal realm, which remains hidden from our limited spatiotemporal perspective. So, if Galilean relativity has told us that physical entities are not inhabiting a substantive objective space, as each entity constructs a personal three-dimensional relational space, Einsteinian relativity has pushed such view a step further, telling us that entities are not only not inhabiting a substantive

[22] For simplicity of the discussion, we will neglect that there are also accelerations experienced by B, at her/his departure, turnaround and arrival.

space, but also that they do not construct their time axis in the same way, i.e., that each entity constructs a personal four-dimensional spacetime. We thus see that, similarly to quantum mechanics, relativity also indicates the existence of an underlying non-spatial and non-temporal realm. And as we are now going to explain, the hypothesis that physical entities would have primarily a conceptual nature is not only able to offer an explanation for the strangeness of the quantum effects, but also for the relativistic ones, which are erroneously considered to be less strange than the former (if we try to understand them by maintaining a purely spatiotemporal perspective).

11 Time dilation

Let us consider again the previous example, assuming this time that A and B are not two different versions of the same person, who made a different choice in the past, but two different physical entities, so that we are now in the specific situation of Langevin's twin-paradox. Note that the reason why it was referred to as a paradox is the fact that one could argue that by considering the viewpoint of the reference frame associated with the space ship, it is the entity remaining on Earth that appears to have performed the return trip. This apparent symmetry between the two descriptions is however broken as soon as one observes that the two reference frames are non-equivalent, as is clear that the frame associated with entity B, using the space ship, is a non-inertial one. In other words, the symmetry is broken by observing that B experiences accelerations that are not experienced by A (neglecting those associated with the rotation of the planet). One should not conclude, however, that the observed time-dilation effect (or length contraction effect, from the viewpoint of the traveling entity) would be caused by these accelerations: it is in fact the geometric structure of the worldlines associated with the two entities that is responsible for the time dilation, which is truly defined by the Lorentz-invariant length corresponding to the so-called *proper time* interval associated with them (Aerts 2017).

The two entities A and B are here considered to be classical macroscopic bodies, i.e., ordinary objects. However, as we discussed in Section 6, in the conceptuality interpretation objects are idealizations of story-like conceptual entities that can be in different meaning-states. So, we want now to consider the two entities A and B not as objects moving in space but, primarily (and more fundamentally), as conceptual entities that can have meaning driven interactions. In relativity, one usually associate observers with entities in different states of motion, where the notion of *observer* is typically understood as a shortcut for a reference frame plus an entity that, if it would be present in some specific location, would be able to perceive (detect, measure) phenomena relative to the viewpoint of that reference frame and specific location.[23] We will also associate observers with the two entities A and B, but we will consider them as mind-like entities sensitive to the meaning carried by A and B. Let us simply call them *cognitive observers* and denote them C_A and C_B. These two observers are however not associated with spatiotemporal frames of reference. The only aspect distinguishing C_A from C_B is that the former is focused on the evolution of A, whereas the latter is focused on the evolution of B.

To fix ideas, we can simply consider that the process of change of state of entity A corresponds to the cognitive activity of entity C_A, reflecting on a given problem, so that the initial state of A would correspond to the *Hypothesis* initiating such reflection, and the final state of A to the *Conclusion* reached by C_A, after having followed a certain number of intermediary *conceptual steps*. And same for the cognitive observer C_B, following the evolution of the conceptual entity B.[24] Here we will assume that C_A and C_B are just witnessing the unfolding of the meanings carried by A and B, as they evolve, i.e., that they are not themselves producing the observed changes of their states. Also, to place ourselves in the "twin-paradox" situation, we consider that C_A and C_B are both reflecting on the same problem, starting with the same *Hypothesis* and subsequently jointly reaching the same *Conclusion*. In other words, in the conceptual

[23] To quote a passage from Einstein (1920) (emphasis is our): "If the observer *perceives* the two flashes of lightning at the same time, then they are simultaneous."
[24] This means that we are here considering A and B to correspond to the conceptual entities *Reasoning of* C_A and *Reasoning of* C_B, respectively.

abstract realm that they both inhabit, they have a first meeting at the "place" of their commonly shared *Hypothesis*, then a second encounter when they reach the same *Conclusion*. The difference between C_A and C_B, however, is that the cognitive path they follow to reach that same *Conclusion*, starting from the same *Hypothesis*, is not the same, in the sense that C_A, focused on the evolution of A, is assumed to use n_A conceptual steps to do so, whereas C_B, focused on the evolution of B, is assumed to use a lesser number of steps $n_B < n_A$. Let us denote A_i, $i = 0,1, \dots, n_A$, the different states through which A passes to go from the *Hypothesis* = A_0, to the *Conclusion* = A_{n_A}, and let us denote B_i, $i = 0,1, \dots, n_B$,, the states B transition through to also go from the *Hypothesis* = B_0, to the *Conclusion* = B_{n_B}.

Imagine then that the cognitive observer C_A, to keep track in an orderly manner of the conceptual path followed by entity A, decides to introduce an axis to parameterize each one of A's conceptual steps. For this, it will ascribe a unit length L_A to such axis, corresponding to a single conceptual step, and it will also assume that the speed at which each step is accomplished is the same for all steps and is equal to a given constant c, so that the duration of a single step is: $\tau_A = L_A/c$. When going from the *Hypothesis* to the *Conclusion*, the reasoning of C_A will thus correspond to a movement of entity A, along such *order parameter axis*, going from an initial point D_0 to a final point $D_{n_A} = D_0 + n_A L_A = c(t_0 + n_A \tau_A)$, where we can define the times $t_i = (D_0 + iL_A)/c$, $i = 0, \dots, n_A$, associated to each step, where $t_0 = D_0/c$ is the initial time and $t_{n_A} = D_{n_A}/c$ the final time. Consider now the evolution of entity B, which we assumed can reach the same *Conclusion* following a shorter conceptual path, only made of $n_B < n_A$ steps, and for simplicity we will consider here that $n_B = n_A/2$. The cognitive observer C_A can also decide to focus on the evolution of B, i.e., might also be willing to keep track of the cognitive path followed by entity B, in addition to that of A. Now, if A and B are entities of the same nature, it can be assumed that when they produce a cognitive step, they do so at the same speed c. But then, since the path followed by B in the abstract conceptual realm is such that it can reach the same *Conclusion* in half the steps used by A, the cognitive observer C_A cannot represent such path on the same axis used to parametrize the path of A, as units on the latter were precisely chosen in a way that one needs twice the number of steps to reach the *Conclusion*.

To consistently parametrize also the evolution of B, C_A is thus forced to introduce an additional axis, and use the additional dimension generated by such axis to describe B as moving on a round-trip path, now contained in a higher dimensional space generated by both the first parametric axis – let us call it the *time axis of* A – and this second parametric axis – let us call it the *space axis of* A. So, the evolution of entity B is described as a movement on a path leading away from such time axis and then coming back to it, to reach the *Conclusion* meeting point, and this by doing exactly $n_A/2$ cognitive steps (see Figure 11).

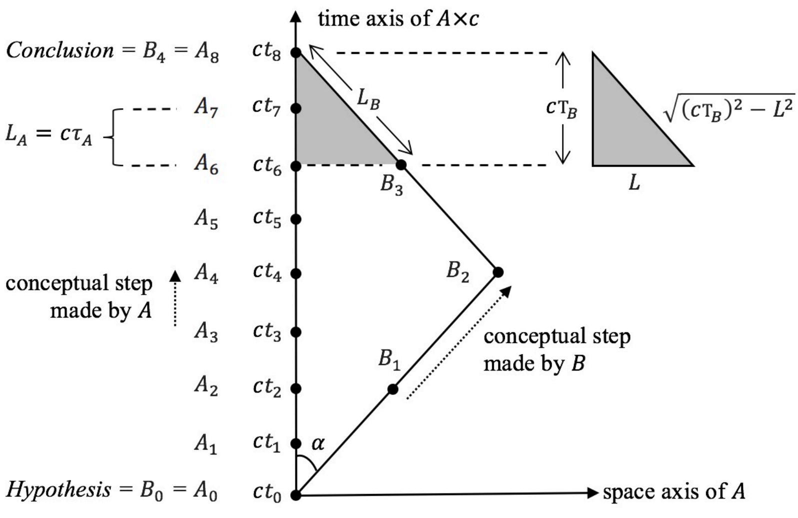

Figure 11 The coordination of the conceptual paths followed by the two entities A and B, in the spacetime constructed by the cognitive observer C_A (here in the situation $n_A = 8$ and $n_B = 4$). When measured along the time axis of A (multiplied by the constant speed c) the length $L_B = cT_B$ of the conceptual steps of B appear to be longer than the length $L_A = c\tau_A$ of those of A. However, when measured along the direction of its own movement in the A-spacetime, using the *Minkowski* instead of the *Euclidean* metric, one finds that the conceptual steps of the two entities are exactly of the same length, in accordance with the fact that they both move at the same (absolute) constant speed c in the underlying conceptual realm.

However, if we consider the construction of this parametric space from a purely *Euclidean* perspective, we immediately see that things do not work. Indeed, if we calculate the length of the B-path using the *Pythagorean theorem*, we will necessarily find a path that is longer than that walked by A.

This would not be correct, as is clear that B follows a shorter conceptual path, only using half of the conceptual steps used by A. Therefore, when measuring the length of B's conceptual path, it should be shorter and not longer than that of A. For C_A to fix this problem, the only way to go is to consider a *pseudo-Euclidean* space, instead of an Euclidean one, and more precisely that specific pseudo-Euclidean space known as the *Minkowski* space (or spacetime), where distances are not calculated using the *Pythagorean theorem*, but a *pseudo-Pythagorean theorem* attaching a negative sign to the squares of the components associated with the space axis, and a positive sign to the square of the components associated with the time axis. In this way, the length of the hypotenuse of a right triangle, whose catheti are associated with the time and space axes, respectively, will generally be less than the length of the time-cathetus. It becomes then possible for the length L_B of a single conceptual step of B (see Figure 11) to be exactly equal to the length L_A of a single conceptual step of A, i.e., to have the equality $L_A = L_B$, which is what C_A wants to have, as the two entities A and B are assumed to change state at the same absolute speed c (the speed of light in vacuum) in their common conceptual realm, so that the duration/length of their conceptual steps must be an *invariant*, i.e., the same for all entities.

More precisely, if L is the component of the length L_B along the space axis of A, then according to the pseudo-Euclidean (Minkowski) metric we have: $L_B^2 = (cT_B)^2 - L^2$, so that the requirement that $L_A = L_B$, or equivalently $L_A^2 = (c\tau_A)^2 = L_B^2$, considering that $\tau_A = T_B/\gamma$ and $c\tau_A = \frac{cT_B}{\gamma} = \sqrt{c^2 - v^2}T_B$, gives: $(c^2 - v^2)T_B^2 = (cT_B)^2 - L^2$, that is, $L = vT_B$. In other words, by adopting a pseudo-Euclidean (Minkowski) metric, the cognitive observer C_A is able to construct a spacetime theater in which it can keep track, in a consistent way, not only of the cognitive process associated with

A, but also of that associated with B,[25] and to do so all it has to do is to attach an appropriate spatial velocity v to characterize its state changes. In other words, the reason for the time-dilation generalized parallax effects becomes clear when the existence of an underlying conceptual realm is taken into consideration: since C_A has to also parametrize the cognitive path of B, and cannot do it using the same time-axis, it has to consider a movement within a higher dimensional space, characterized by an angle $\alpha = \tan^{-1}\frac{v}{c}$ with respect to the direction of the movement of A. This will inevitably introduce *temporal effects of perspective*: C_A will observe B as if it was producing conceptual steps (or cycles) having an increased duration $T_B = \gamma\tau_A$. This means that C_A, focusing its attention on A, when it compares its cognitive activity with that of an observer C_B, focusing its attention on B, will have the impression that C_B reasons more slowly than itself, but since it also reasons more efficaciously, as it uses a lesser number of conceptual steps, they are nevertheless able to meet at the common *Conclusion* state. This is just how things appear to be at the level of the spacetime parametrical construction operated by C_A. At the more objective level of the non-spatiotemporal conceptual realm, A and B move at exactly the same speed c, which is the intrinsic speed at which they both perform their conceptual steps.

Our description of time-dilation effects would of course require more explanations, and we refer the reader to Aerts (2017), where more details can be found. Our main point here was to highlight that relativity theory, similarly to quantum mechanics, indicates the existence of a non-spatiotemporal conceptual realm. As we mentioned already, our discussion indicates that its non-temporality is however not to be understood in the sense of an absence of processes of change. On the contrary, every conceptual (physical) entities would incessantly change state, i.e., produce new conceptual steps, by all "surfing" over the conceptual realm at the light speed c. Therefore, at a more fundamental level, movement would be incessant, and in a sense absolute. This is possible because it is not a movement in space and time, as space and time would only emerge

[25] A single spatial axis is sufficient when considering only two entities. However, additional space axes are needed if further entities are considered; see Aerts (2017).

when a cognitive observer decides to coordinate the evolution of a given conceptual entity with the evolution of other conceptual entities, introducing for this a specific Cartesian coordinate system. In such system, the time axis orders the conceptual changes of the entity the cognitive observer decides to primarily bring its focus to, whereas the spatial axes order the evolution of the other conceptual entities, relative to such proper time-axis, by representing them as movements in space. Such spatiotemporal construction, to be consistent, requires the metric to be Minkowskian, which of course remains counterintuitive to us humans, as we evolved on this planet by mostly interacting with entities moving extremely slowly in space with respect to one another, i.e., that are almost at rest with respect to one another, so that the relativistic parallax effects, being negligible, were not integrated in our mental representation of the world.

Of course, this spatiotemporal representation only works for conceptual entities having reached the status of objects, the so-called classical macroscopic bodies. When micro-physical entities are considered, the time-space duality must be replaced by a more general duality between time and the set of outcome-states associated with the different possible measurements. This is for instance the situation where the cognitive observer C_A would not merely witness the surfing of entity A over the more fundamental conceptual realm, but in fact would also affect its surfing through its observation, thus also introducing in its evolution the additional ingredient of indeterminism. Note that the possibility for C_A to also act as a quantum measurement context for entity A is not incompatible with the special situation of a deterministic evolution. Indeed, any deterministic change of state can in principle be conceived as being the result of a measurement having just a single possible outcome.[26] This means that deterministic evolutions can in principle be described as recursive applications of multiple one-outcome measurement processes. Some of these processes will be governed by classical contexts, and the corresponding deterministic evolution can be described as an 'evolution in space', others will be governed by genuine quantum contexts, and the corresponding deterministic evolution cannot be described as happening in space, but in a more abstract (conceptual)

[26] Hence, two-outcome measurement processes would not constitute the simplest imaginable measurement situation.

non-spatial (and non-temporal) realm.

We already mentioned in Sections 7 and 9 the extended Bloch representation (EBR) of quantum mechanics (Aerts and Sassoli de Bianchi 2014a, 2016b, 2017a), which can be used to construct a quantum theater in which all the measurement processes associated with a quantum entity, and its states, can be jointly represented. For measurement contexts admitting sets of up to N possible outcome-states, the number of required dimensions for the associated Blochean quantum theater is equal to $N^2 - 1$, which is the number of generators of the $SU(N)$ group of transformations. Roughly speaking, these transformations can be interpreted as "generalized rotations," and this means that to enter such Blochean theater one has in a sense to "rotate away" the intrinsic complexity of a quantum entity, by means of these generators. A human conceptual analogy here would be that of considering that to enter a given space of discourse, like that of a political agenda, certain concepts first need to receive a "twist." Our spatiotemporal theater, considered as a specific space of discourse, would require in the same way specific "twists" to be applied, for the different quantum conceptual entities to enter and be representable in it.

We conclude our discussion about relativistic effects with a brief remark about gravitation. As is well known, we are still lacking a satisfactory quantum gravity theory, and this because the fundamental forces in the *Standard Model* of particle physics are modeled as (quantized) fields in a fixed spatiotemporal background, whereas the gravitational forces precisely affect that background, making it a dynamical one. Different from the Standard Model and similar approaches, attaching a fundamental role to the spatiotemporal canvas, the conceptuality interpretation posits that reality is not contained in spacetime, the latter being just a relational construction emerging each time a very specific interface is considered: that between the macroscopic pieces of matter and the force fields acting on them, i.e., between the fermionic constructions and their bosonic way of exchanging meaning. It is in this interface that the illusion was formed of a spatiotemporal theater in which our physical reality would be fully contained; an illusion which was then consolidated through the very scientific experimental method, somehow forcing us to only approach our physical reality through such interface, as is clear that physicists, in their laboratories, always collect data from experiments involving apparatuses formed by macro-pieces of matter. If space and time (we should better say spaces and times) are by-products of this very specific interface, we can more easily understand the reason of the difficulties that were encountered in the attempts to construct a consistent quantum gravity theory. The conceptuality interpretation, by pointing to the existence of a more fundamental and abstract realm, in which the physical conceptual entities evolve, the fundamental forces, gravity included, are then allowed to be understood as expressions of the different ways conceptual entities can exchange meaning, and because of that be brought together, or apart.

12 Conclusion

It is time to move towards the conclusion of our *tour d'horizon* of the conceptuality interpretation and its explicative power. In this last section, we will just evocate some possible directions for subsequent investigations, and in this regard, we also refer the interested readers to Aerts (2009, 2010a, b, 2013, 2014).

Concerning the so far failed tentative to unify gravitational and quantum elements of reality within a unique consistent theoretical construction, which we mentioned in the previous section, let us observe that the conceptuality interpretation brings another interesting line of reflection: it is also a possibility that a single 'quantum plus gravitational' description might not be feasible, in the sense that 'quantum' and 'gravity' could very well be incompatible descriptions, in the same way that position and momentum measurements are incompatible experimental contexts. Indeed, a conceptual reality is also a contextual reality, i.e., a reality where certain meanings would be actualized and actualizable only in certain contexts, and not in others. In that respect, classical physics can also be understood as a description emerging from a very specific context, produced by us humans mostly manifesting and interacting with physical entities through our macroscopic dense bodies. Standard quantum mechanics, and more precisely its formalization through the Hilbertian formalism, can be considered as another context associated with different operationally posed questions, whose answers cannot be all organized in the 'space of relations' that resulted from the previous classical construction, forming a sort of closed representational environment [somehow in the spirit of Heisenberg's notion of *closed theories* (Bokulich 2008)]. But the quantum representation, which also has its structural shortcomings, might as well form another closed environment, considering for instance its inability to describe entities that can remain separated in experimental terms (Aerts 1984, 2014; Aerts and Sassoli de Bianchi 2017b,c). In other words, it is also possible that a single encompassing representation could not be obtained, precisely because it would correspond to the unrealistic desiderata of simultaneously actualizing properties/meanings that are in ultimate analysis associated with incompatible contexts.[27]

In addition to that, the conceptuality interpretation, with its hypothesis that physical entities are fundamentally conceptual, also fosters a *pancognitivist* view (as was mentioned in the Introduction), where every element of reality would in fact participate in cognition, with human cognition being just a special case of it, appearing at a very particular organizational level. This has clearly deep consequences on our view about *evolution* in general, as the advent of the biological species on our planet, including the human one, would only be part of a much wider and fundamental process of change resulting from the interaction of conceptual entities with the countless cognitive structures that are sensitive to their meaning, and this since the dawn of the formation of our universe and at different levels of the same. If this is correct, the default picture we should adopt in the description of our evolving physical reality is that of a huge and multilayered *cultural evolution* (Aerts and Sassoli de Bianchi 2018). So, in the same way we humans use concepts and their combinations to communicate and evolve our cultures, the same might have occurred, and would still be occurring, in the micro-realm, and this automatically provides a compelling explanation for so-called *dark matter*, which can then be understood as that part of matter which, as an interface, has not co-evolved together with the bosonic "messenger" entities. Think of the abundance in our human

[27] This is a view that subtends a notion of realism that was recently introduced and called *multiplex realism* (Aerts and Sassoli de Bianchi 2017b,c).

environment of those structures that cannot exchange human meaning, i.e., the ordinary pieces of matter as opposed to the cultural artifacts, the former being much more abundant than the latter. The same could be for dark matter, as opposed to ordinary matter, which not only does not interact with the bosonic micro-carriers of meaning, but also appears to be indeed much more abundant. On the other hand, gravity, by working at a very different scale than all the other forces, would possibly describe a more ancient way of exchanging meaning and creating concentrations of it; a way which has remained in common with both ordinary and dark matter.

This special role played by gravitation can also be seen in the diversity of the mass values of the different micro-physical entities, which are not just multiples of some fundamental unit, as it is the case for instance for the electric charge. This seems to suggest that mass is not so much connected to the notion of *identity* of a given conceptual entity, but instead to the different possible ways a given identity is able to manifest. Think of the puzzling existence of the three different *generations of elementary micro-entities*. Entities that are members of these different generations interact exactly in the same way but differ in their masses. To give an example, there are three different electronic entities: the ordinary *electron* of the first generation, having a mass of $0.511\ \mathrm{MeV/c^2}$, the *muonic* electron of the second generation, having a larger mass of $106\ \mathrm{MeV/c^2}$, and finally the *tauonic* electron of the third generation, with an even larger mass of $1777\ \mathrm{MeV/c^2}$ (almost twice the mass of a proton). The conceptuality interpretation offers the following possible element of explanation for these different generations of micro-entities: they would simply correspond to different energetic realizations of a same conceptual entity, in the same way as in our human culture a concept can manifest as, say, a spoken sound-energetic form, an electromagnetic and/or electronic form, in a carved into stone form, etc., and all these different forms, although they have different mass-energies, they nevertheless always convey the same meaning, i.e., they interact in a meaning-driven environment in exactly (or almost exactly) the same way.

Let us for a moment also mention the issue of the observed intrinsic expansion of the universe, according to current Big Bang theories. The recurring question is: "In what the universe is expanding into?" And the recurring answer is: "This is a nonsensical question, as the universe contains everything and there is nothing into which it could be expanding, so, it is just expanding!" Of course, this kind of answer is perceived as highly unsatisfactory to the layman, and rightly so, as we think it should be unsatisfactory to the professional physicist as well. As we discussed at length in this article (Aerts 1999): "Reality is not contained within space. Space is a momentaneous crystallization of a theatre for reality where the motions and interactions of the macroscopic material and energetic entities take place. But other entities – like quantum entities for example – 'take place' outside space, or – and this would be another way of saying the same thing – within a space that is not the three-dimensional Euclidean space." The conceptuality interpretation allows one to push even further this statement, by observing that reality's non-spatiality results from it being of a fundamental conceptual nature, implying the existence of a multilayered structure resulting from the interplay between states having different degrees of abstractness and concreteness.

In other words, the expansion of our universe would simply be the result of a cosmic-cultural evolution constantly creating new stories (through a mechanism of conceptual combination), which emerge from a substrate of more abstract entities (i.e., conceptual entities in more abstract states) that can combine together to form more complex states. To draw a parallel with the Web, think of the constant creation of new webpages, arising from the activity of all cognitive entities participating in the associated human meaning-driven interactions. In that respect, it is interesting to observe that the expansion of the Web, since the first web-site was published back in 1991, has been an accelerated one, so one can also think of the observed increasing rate of expansion of our universe to be the result, *mutatis mutandis*, of a cultural accelerated growth mechanism. Let us also mention that a conceptual reality also points to the possibility of multiverses (not in the sense of the many-worlds interpretations), as is clear that stories sharing common meanings can form aggregates, and that some of them might have formed a very long time ago, around an initial "seed concept." Just to offer another analogy, think of so-called "shared cinematic universes" of our recent years movie culture: each shared cinematic universe contains a growing number of films (stories) that are all meaning connected, focusing on different characters or group of characters, but all part of a same coherent and non-contradictory continuity. On the other hand, stories about characters in a given cinematic universe will never appear in another one, and if "crossovers" nevertheless happen (think of DC Comics' Superman possibly meeting Marvel Studios' Spider-Man), the associated stories will be usually considered to be non-canon, i.e., more abstract states of the characters involved, for instance described as alternate realities, "what if" scenarios, jokes and gags, dreams, etc.

When it comes to our spatiotemporal universe and its vastness, the question of the possible presence of intelligent extraterrestrial life also arises in a natural way, also because the majority of scientists is convinced that intelligent extraterrestrials populate space, resulting in various scientific programs that over time have been funded for the search for intelligent life. As Carl Sagan used to say, in a famous science-fiction novel (Sagan 1985): "The universe is a pretty big place. If it's just us, seems like an awful waste of space." Space, however, would only be the tip of the iceberg of a realty whose spatiotemporal manifestation would only correspond to a thin layer of it. We can of course explore "in width" such layer, which certainly is a vast territory if considered from our human limited perspective, but following the view that we have expressed in the present article, there is another territory, incredibly wider, which is about exploring reality "in depth," in the direction of its more abstract states. This is what physicists have begun to do when designing refined experiments about the many different quantum and relativistic effects. These experiments, and the associated efforts to describe their outcomes by means of a suitable formal language,[28] can be seen to be our first primitive steps in learning a non-human and more universal proto-language, so perhaps it will be by exploring reality along this "in depth" direction that contacts with extraterrestrial (extra-dimensional) intelligence will firstly occur, if they have not already occurred (Aerts and Sassoli de Bianchi 2018).

Let us also mention John Wheeler's famous "it from bit" epitome,

[28] The unreasonable effectiveness of mathematics in the natural sciences (Wigner 1960) becomes all of a sudden less unreasonable if we consider that mathematics is first of all a sophisticated conceptual language and that physical entities interact in a language-mediated conceptual way.

which he used to indicate that (Wheeler 1989): “all things physical are information-theoretic in origin,” in a participatory universe. The conceptuality interpretation completes Wheeler’s account in two different ways. First of all, by extending the notion of participant, which is not limited to humans creating meaning by operating measurement devices, as the latter (and more generally, all pieces of matter) would themselves be meaning-sensitive entities able to exchange information, independently of the presence of the human consciousnesses. Secondly, by observing that “bit,” understood as a unit of measure in meaning exchanges, is not what combines to construct the physical entities of our spatiotemporal environment, or to more generally produce the different physical phenomena.[29] What combines is not the bits of information, but the conceptual entities carrying such information, which participate in a grand conversation where the different cognitive participators, at different organizational levels, constantly exchange streams of meaningful information. So, following Wheeler’s desiderata to synthesize the central point of quantum theory (and, we also add, of relativity theory) in a simple and concise statement that anyone could understand, we believe that such statement might be: *the stuff the world is made of is conceptual.*

To conclude, it is important to note that the conceptuality interpretation also contains an explanation that would make our physical reality intelligible again to human pre-scientific intuition and thinking. This certainly distinguishes it from all the other interpretations, and also confers to it a highly speculative character, at least at the present state of our investigation. In that respect, it is important to mention again how crucial it is not to confuse the human conceptual realm with the conceptuality that would be inherent in our physical world. In pre-scientific times, in order to make sense of the physical entities and associated phenomena, we humans tried to psychologize them, conferring them human-like mental attributes, motivations and behaviors. According to the conceptuality interpretation, by doing so we committed a serious mistake, but at the same time we also accessed a deep insight about the physical world. The deep insight is the recognition that the latter would share with our human cultural world a same conceptual/cognitive nature; the

[29] We cannot combine cubic meters to build a house, although its volumetric properties can certainly be expressed in such units.

serious mistake is about believing that physical entities and human cognitive/conceptual entities would exchange the same kind of meaning. This is the same kind of mistake we committed when we believed that planet Earth was fixed at the center of the universe, which was then reduced to a mere celestial sphere with the stars attached to it. When we escaped this "Ptolemaic cave," following the Copernican revolution, we accessed an incredibly wider and richer universe. Similarly, by escaping the "cave of our human-centered worldview," following the "conceptuality revolution" (if it will turn out to be such), we might also access an incredibly deeper and richer reality, requiring us to learn not only new languages, but also the non-human semantics attached to them.

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Taking quantum physics and consciousness seriously: what does it mean and what are the consequences?

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Abstract

We present some of the foundational ideas of so-called *hidden-measurement interpretation* of quantum mechanics, whose proposed solution to the measurement problem does not require any *deus ex machina* intervention from an abstract ego, but asks in exchange to accept that our physical reality would be mostly *non-spatial*, and therefore much larger than what we could expect from our ordinary experience of it. We also emphasize that, similarly to quantum mechanics, the data today available from the study of psychic and spiritual phenomena about the consciousness, if taken seriously, require us to accept, as well, the existence of a non-spatial "elsewhere" where the consciousness is able to manifest. In other terms, both quantum physics and consciousness point to the existence of larger realities extending beyond the limits of our spatial theatre. This doesn't mean, however, that they would necessarily be the same realities, as is often assumed due to prejudices rooted in materialism. We also explain how the new research domain called *quantum cognition* has provided a new thought-provoking model for the non-spatial nature of the microscopic entities, in what has been called the *conceptuality interpretation* of quantum mechanics, and how the astonishing hypothesis underlying this interpretation can possibly shed some light also on the nature of those non-ordinary phenomena that we humans are able to experience when in more expanded states of consciousness.

1 Introduction

Nowadays, a bookseller receiving a new book on quantum physics may be in doubt whether to put it on the shelf dedicated to physics, or on that devoted to spirituality. This "dilemma of the bookseller" perfectly illustrates the confusion often existing among laymen, but also among some experts, regarding the fundamental differences of certain fields of inquiry, such as modern physics and spirituality, and more specifically quantum mechanics and the study of consciousness.

Part of this confusion can certainly be considered as the fair price to be paid in the process of creation of a more global and unitary vision of our reality, both inner and outer. On the other hand, it is important not to forget that a non-illusionary process of unification of different disciplines can only be realized if based not so much on the recognition of their similarities, but above all of their differences, as only then it becomes possible to build solid bridges between them, by promoting a vision that is truly interdisciplinary and, whenever possible, 'transdisciplinary'.

The vaguely defined concept of "quantum consciousness," today quite trendy, perfectly exemplifies this difficulty. In fact, although the majority of scientists are convinced that no one understands quantum mechanics and consciousness, this does not seem to prevent their use in combination with the hope that the superposition of two mysteries will produce an explanation. We do not mean by this that quantum physics will be unable to promote a better understanding of the phenomenon of consciousness, and vice versa. However, we are convinced that this "cross-fertilization" will become possible only to the extent that both fields will be taken with due seriousness.

To take quantum physics and consciousness seriously means to fully address the challenges with which they confront us and accept without biases the world-views that follow. Only then it becomes licit to ask whether some of the similarities that are shared by both quantum physics and the manifestation of the consciousness are only apparent, or the expression of a deeper isomorphism. It is the main purpose of the present article to highlight the importance of this methodological approach, and its consequences, in our attempt to construct a more mature vision of reality.

2 Mixing quantum and consciousness

Quantum physics and the *study of consciousness* are undoubtedly two fundamental fields of inquiry. They are fundamental when considered individually, as they study different aspects of our reality, but also when considered in combination. Many researchers still feel that it is not possible to understand quantum physics, or rather the reality that this theory reveals to us, without involving the consciousness and, conversely, that it is not possible to understand the phenomenon of the consciousness without involving, in some way, quantum physics.

To give a typical example, some scientists believe that the central problem of quantum physics, the so-called *measurement problem*, can only be solved by assuming the existence of an extra-physical agent – precisely, the consciousness – that can transform the abstract probabilities into concrete actualities, in what is usually called the *collapse* (or *reduction*) *of the wave function*. This thesis was defended in the past by some famous physicists, such as *John von Neumann* (1932), *Fritz London* and *Edmond Bauer* (1939), *Eugene Wigner* (1961) and more recently, for example, *Henry Stapp* (2011), just to mention some of the best-known names.

Sometimes called the *von Neumann-Wigner interpretation*, this view is often confused (especially by non-experts) with the *Copenhagen interpretation*, and surprisingly it still collects some credit among some physicists and philosophers of science. It also remains the preferred interpretation of many parapsychologists who study the interaction between mind and matter-energy, for example in the so-called phenomenon of *psychokinesis*; see for instance Radin (2012) and Sassoli de Bianchi (2013e).

Conversely, and to make another symbolic example, there are scientists who believe that the central problem in the study of consciousness, the so-called *hard problem*, to use the terminology of philosopher *David Chalmers* (1995), can only be solved by assuming that our brain functions as a pure quantum entity, that is, as a system governed by coherent, non-local and non-computational processes, where the mysterious collapse of the wave function would again play a crucial role in allowing the phenomenon of the consciousness to manifest in the here-and-now of our existence.

There are different models of the hypothesis that the consciousness, understood here also as conscious mental activity, is the product of non-classical processes (in the sense of classical physics). One of the most well-known models is that of the physicist *Roger Penrose* and anesthesiologist *Stuart Hameroff*, called *Orch-OR* (*orchestrated objective reduction*), where one assumes a connection between certain quantum biomolecular processes, taking place in specific structures of the brain (the microtubules) and the alleged structure of space-time below the Planck scale, which would be responsible (according to Penrose's interpretation) for the collapse of the brain wave function (Hameroff & Penrose, 1996).

It is important to note that, contrary to the examples mentioned above, the majority of physicists do not consider that the problems of quantum physics can be solved with a simple *ex machina* intervention on the part of the consciousness. Similarly, most cognitive scientists do not consider that the problems of the consciousness can be solved with a simple *ex machina* intervention of quantum physics, through the hypothesis of the quantum brain. This does not mean, of course, that the understanding of the phenomenon of consciousness cannot shed some light on the nature of physical entities as well, or that the understanding of quantum physics cannot help us understand the working of the human mind (and not only), especially with regard to the structure of the thought and decision-making processes. It means only that scientists are today generally not willing to increase, without due reasons, the number of entities required to explain a phenomenon, in accordance with the famous principle of *Occam's razor* (no more than necessary).

We are in agreement with this line of thought, in the sense that we believe that quantum physics does not require any *ad hoc* intervention of the consciousness to be explained, and that the hypothesis of the quantum brain, as stated above, is not necessary to elucidate the phenomenon of the consciousness. On the other hand, we think it is highly desirable, if not necessary, to take quantum physics and consciousness very seriously, which most scientists today seem to not be willing to do yet.

3 Taking quantum physics seriously

We will start by explaining what we mean by the statement: "taking quantum physics seriously." For this, it is important to remember that in quantum mechanics, as opposed to classical mechanics, the state of an entity can evolve according to two very different modalities. The first modality is a purely *deterministic* one, described by the famous *Schrödinger equation*, which characterizes the processes of change of isolated systems; see Figure 1.

The second modality, absent (or rather, not considered) in classical physics, is a purely *indeterministic* one, described by the so-called *projection postulate*, which characterizes those changes that are produced by the *observational processes*, i.e., by the *measurement processes* (we will use these two terms interchangeably in this article) of the different *physical quantities* associated to a physical entity (also called *observables*); see Figure 2.

Although a measurement process is inherently indeterministic, it is nevertheless possible to calculate with great precision the probabilities of the different possible outcomes, using a particular mathematical formula, known as the *Born rule*. In other words, although it is not possible to predetermine into what the wave function will collapse, the theory nevertheless allows us to determine the probabilities associated with the different possible collapses.

It is worth pointing out that the wave function Ψ has little or nothing to do with a wave propagating through space: it is a mathematical object, belonging to a specific mathematical space, the so-called *Hilbert space*, whose role is to describe the *state* of the physical entity in question, i.e., the *set of its properties*. More appropriately, it should therefore be referred to as the *state vector* (being the Hilbert space a *vector space*), but in this article we will continue to use the more well-known term of "wave function."

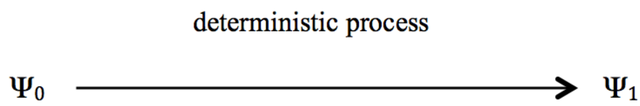

Figure 1 A process is called *deterministic* if it is the expression of a context that changes the initial state Ψ_0 of a system into a single possible final state Ψ_1, which in principle is predictable in advance.

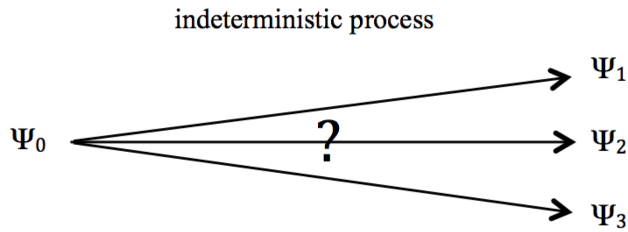

Figure 2 A process is called *indeterministic* if it is the expression of a context that changes the initial state Ψ_0 of a system into one of several possible states, for example Ψ_1, Ψ_2 and Ψ_3, in a way that is not predictable in advance, not even in principle.

Of course, much more needs to be said to complete the "quantum pie" recipe, which is formed by a number of other key ingredients, but right now let us focus on the purely indeterministic process described by the wave function's collapse. To take quantum physics seriously means, among other things, to take seriously this specific *reduction* process. Namely, to consider the wave function's collapse a perfectly *real physical process* which takes place every time a quantum entity is observed, in the practical sense of the term, that is, whenever a given physical observable, such as the *position observable*, is concretely measured by means of an appropriate measuring instrument.

To consider that a quantum measurement process is a real physical process, means to consider that the state change it produces is an *objective* physical change by which new properties are truly *created*, and others are necessarily *destroyed*. This means that a quantum observational process is not just a *discovery process*, but also in part, a *creation process*. Not only is this because it is able to bring into existence those same properties it is meant to observe, but also because this happens in a way that cannot be predicted in advance by the observer-experimenter, not even in principle, that is to say, in a purely indeterministic way.

The fact that quantum observational processes are indeterministic does not mean, however, that they would be arbitrary. In fact, if you repeat the same measurement process many times, using identical entities always prepared in the same initial state, the obtained statistics of outcomes will necessarily obey the aforementioned Born rule, namely, the *quantum probabilities* that this rule allows one to calculate as a function of the initial state. For this reason, a measurement process, while creating new properties, also allows one to acquire information about the state of the system prior to the measurement, and in this sense, it should also be considered a discovery process.

To take quantum physics seriously is to recognize that a measurement process requires the intervention of the mind (or consciousness) of the observer *only* in two specific moments. The first intervention, of an *active* kind, corresponds to the *choice* of executing a specific observational experiment. Indeed, an observation always involves, upstream, an act of choice: the choice to observe a given property, or physical quantity, rather than another, creating for this a specific experimental context.

The second intervention, of a *passive* kind, is simply to take note of the outcome of the measurement process, once it has been completed, for example, reading the value indicated by a pointer on a dedicated dial, or identifying a luminous spot on a screen detector, or the radius of a trail in a *Wilson chamber*, etc.

The nature of these two interventions is usually well understood and they do not require special explanations. Indeed, it is quite natural to assume that the state of a physical entity, either microscopic or macroscopic, cannot in any way be affected by the investigator's choice to perform a measurement rather than another, or by the fact that once the observation is completed, s/he can take knowledge, or not, of its outcome.

To take quantum physics seriously means to recognize that the collapse of the wave function is a process that takes place *after* the experimenter has chosen which measurement to execute and is completed *before* the experimenter takes (or does not take) note of its result. In other words, it means to recognize that the collapse of the wave function is a process that has its origin in the interaction between the instrument of observation and the observed entity.

Therefore, resisting the temptation to field extra systemic entities such as the consciousness of the experimenter, to take quantum physics seriously means: *to make the cognitive effort of identifying a physical mechanism that can explain how the quantum probabilities can emerge from the interaction between the measuring instrument and the measured entity*. In other words, it comes to building a *model of interaction* sufficiently general and universal from which the famous Born rule can be derived.

4 Objective collapse theories

There are few approaches that, under the assumption that:

(1) the wave function describes the real state of a physical entity, and not our knowledge of its state;
(2) the collapse of the wave function is an objective process of the change of state, and not just a subjective process of the acquisition of knowledge on the part of the experimenter;
(3) the consciousness of the experimenter does not play any causal role in the collapse;

have been able to provide models that can explain what could possibly happen, "behind the scenes," during a quantum measurement process. As far as we know, there are actually only three specific interpretations of quantum physics that include the three conditions mentioned above. Curiously, all three of these interpretations have been "synchronously" reported for the first time in 1985, and all three were subsequently published for the first time in a physics journal in 1986. More specifically, we are referring here to:

(a) the so-called *objective collapse theories*, whose first version (called *GRW theory*) was proposed by the three Italian physicists *Giancarlo Ghirardi*, *Alberto Rimini* and *Tullio Weber* (1985, 1986), of which a gravitational variant was also proposed by *Diósi* (1989) and *Penrose* (1996);
(b) the *transactional interpretation*, proposed by the American physicist *John G. Cramer* (1985, 1986), which in recent times was further elaborated by *Ruth E. Kastner* (2013);
(c) the *hidden-measurement interpretation*, proposed by the Belgian

physicist *Diederik Aerts* (1985, 1986), which has had over the years different degrees of development; see Aerts & Sassoli de Bianchi (2014) for some recent progresses.

Of course, we cannot, in the limited space of this article, explain how these three approaches aim to solve the quantum measurement problem, in what they are similar and in what they are substantially different. We personally believe that the most promising one is the hidden-measurement interpretation, to the development of which the present author has also recently contributed (Sassoli de Bianchi, 2011, 2012a, 2013a–d, 2014, 2015; Aerts & Sassoli de Bianchi, 2014, 2015a–c). In addition to its simplicity and universality, we think that the ideas behind this interpretation constitute a real paradigm shift, able to fertilize many fields of knowledge, and not only that of physics (Aerts & Sassoli de Bianchi, 2015a,b).

In the next section, we will introduce in simple terms the underlying paradigm of the hidden-measurement interpretation, emphasizing what its consequences are for our conception of the physical world. To do this, and avoid unnecessary technicalities, we will make use of a very simple example.

5 The hidden-measurement interpretation

Imagine holding an object in your hands, such as a vase, and that your intention is to measure its *solidity*. To do this, you have to conceive an observational test that will define in operational terms the property of solidity. There are, of course, different possible definitions, but let us assume that after you have consulted with some colleagues, you have arrived at the following consensual definition of solidity: "a vase possesses the property of solidity if, when it is dropped from a height of exactly half a meter, onto a Persian rug, it will not break."

Now that you have defined with precision the property of solidity (of course, you can be much more precise in the description of the experimental protocol, but for our discussion it will be more than enough), you may wonder, contemplating the vase that in this moment is in your hands: *Is it a solid vase, or a non-solid (fragile) one*? According to the *reality criterion* formulated by *Albert Einstein*, *Boris Podolsky* and *Nathan Rosen* (1935) [see also the discussion in (Sassoli de Bianchi, 2011)], to answer this question it is sufficient to be able to *predict with certainty*, in advance, the outcome of the observational test.

For some vases, depending on the material with which they are made, such a prediction is surely possible, in the sense that it is definitely possible to predict in advance, with certainty, what will be the outcome of the test, and therefore establish whether the vase in your hands has the solidity property, or the inverse fragility property. In other words, with some vases the following alternative will be perfectly valid: (a) the vase has the solidity property, or (b) the vase does not have it. To say that the vase has or does not have this property, means that the outcome of the test, whatever it will be, is entirely *predetermined*, and it is precisely because it is predetermined that you can assign the property of solidity, or of fragility, to the vase, even before proceeding with its experimental observation.

However, to believe that any experimental situation would be of this type, i.e., that the outcome of a test would always be predetermined, is nothing but a prejudice, called the *classical prejudice*, which has been largely falsified by quantum physics. But the groundlessness of this prejudice can be evidenced not only in the observation of microscopic entities, but also of macroscopic ones, such as our vase. Indeed, there is no doubt that vases exist, built with specific materials, for which it is impossible to determine in advance the outcome of the solidity test.

To understand the reasons for this impossibility, it is important to recognize that the outcome of the test will depend on, among other things, how the vase is oriented with respect to the ground when it is dropped from the predetermined height of half a meter. So far, nothing strange: the different possible orientations of the vase describe its different possible states; for some of these states (orientations), the vase turns out to be solid, that is, it will not break if dropped, while for others it will prove to be non-solid, that is, it will break if dropped.

Thus, we can say that if the experimenter can perfectly know the state of the vase before dropping it to the floor, that is, its specific orientation, its shape and the material with which it was made, in principle s/he should be able to predict with certainty the outcome of the test, even before running it. In other words, in this case we would still be in the domain of validity of the classical prejudice: given a specific vase, in a specific state, it will be either solid or non-solid (fragile), and there are no other possibilities.

In the technical jargon of quantum physics, the states for which the measurement produces an outcome that is certain in advance, are called *eigenstates*. For the measurement of solidity, since there are only two possible outcomes (the vase breaks, or does not break), there are consequently only two kinds of eigenstates: those that characterize the solidity of the vase and those that characterize its fragility. If we represent these two kinds of states in a *state space*, we would obtain two different regions: one containing the solidity eigenstates, and one containing the fragility eigenstates.

On the other hand, whenever we consider two distinct regions, automatically we also have to consider their border region, which by definition possesses both of the characteristics (or none of the characteristics) of the two regions it separates. When a vase is in a state that belongs to the border region between the region of solidity and the region of fragility, the classic prejudice does not apply anymore, since it is no longer possible to determine in advance the outcome of the observational test. In quantum physics, these particular states are called *superposition states* and describe a dimension of *potentiality*.

We can use the simple example of the vase to try to understand (and partly demystify) the nature of a state of superposition. Imagine that the vase lies in your hands in a solidity eigenstate, that is, oriented in such a way that if you let it fall to the ground, for sure it would not break. From that state, you can change the orientation of the vase (i.e., its state), until you obtain a fragility eigenstate. But in doing so, you will have to cross the border region that separates the solidity states from the fragility states (see Figures 3 and 4).

Imagine then giving the vase an orientation such that its state is precisely in the intermediary region between solidity and fragility. What will happen when you drop it? To answer this, you need to understand that such a state describes a *condition of instability*, with respect to the observational test in question. In fact, the smallest fluctuation produced by your hands, when you drop it, will cause the vase to land either on a breaking point, or on a non-breaking point, and since you are not able to control these infinitesimal fluctuations of your hands (and the experimental protocol requires you to use your hands, and not some other instrument) the outcome will not be predictable for you anymore.

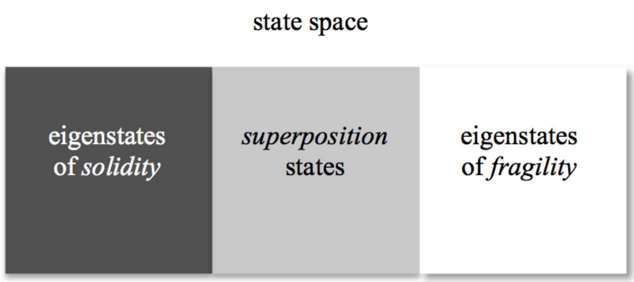

Figure 3 A symbolic representation of the *state space* of the vase-entity. The white region contains the fragility eigenstates, the dark gray region the solidity eigenstates. The in between region, in light gray color, contains the superposition states, for which the outcome of the observational test can no longer be predicted in advance.

It is important to understand the nature of these fluctuations. Each time the experimenter drops a vase the process itself is deterministic, being the result of a specific interaction that occurred between her/his hands and the vase, which is perfectly deterministic. But when the experimenter repeats the experiment with an identical vase, always in the same state, even if s/he tries to proceed in an identical manner, inevitably s/he will drop the vase in an imperceptibly different way. In other words, unconsciously s/he will select (i.e., actualize) a slightly different interaction between her/his hands and the vase.

This difference will have no effect on the outcome of the test if the initial state of the vase lies in the solidity region, or in the fragility region, but the situation is quite different when the initial state of the vase is located in the border region between them. In fact, for these "border states" the smallest variation in the interaction produced by the hands of the experimenter will either cause the vase to break or not to break.

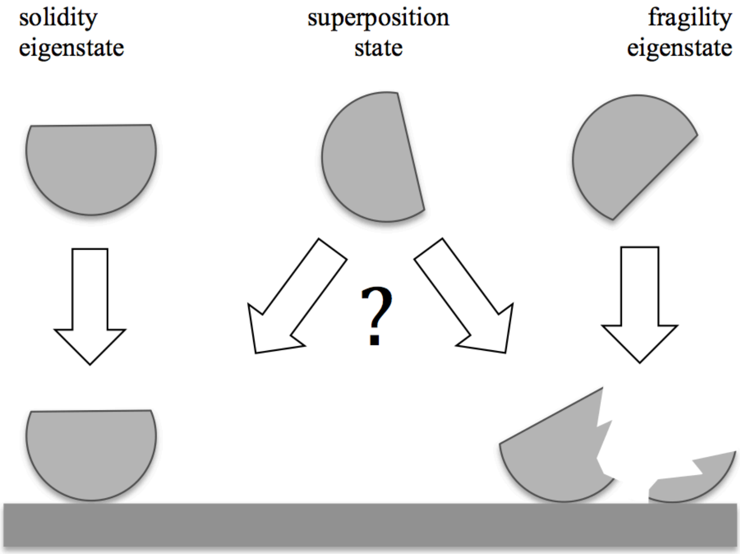

Figure 4 A symbolic representation of the three different kinds of state of the vase, relative to the solidity observational test. A solidity eigenstate corresponds to an orientation of the vase such that, by falling, for sure it will not break; a non-solidity (fragility) eigenstate corresponds to an orientation of the vase that with certainty will cause it to break. A superposition state, between solidity and fragility, corresponds to a critical orientation, such that the smallest fluctuation, when the vase is dropped to the floor, can cause it to either break or not to break.

The attentive reader will have already grasped the profound analogy between the situation described here and what happens during a quantum measurement, for example with elementary microscopic entities. In fact, the observational experiment with the vase reveals an extremely important and universal aspect of a measurement processes: since each measurement process is the result of an interaction between the measured entity and the measuring instrument, and being that this interaction is necessarily subject to fluctuations, each new measurement of a physical quantity will necessarily be a *different measurement*, although externally it may appear identical to the previous ones.

Of course, we repeat it once again for sake of clarity, when the entity is prepared in an eigenstate of the measured observable, i.e., in a state that is *stable* with respect to the mentioned fluctuations, these fluctuations will have no effect on the final outcome of the observation. But when the system is in a state of superposition, that is, of instability with respect to said fluctuations, as infinitesimal as they may be, they will have the capacity to produce outcomes that each time can be different and completely unpredictable.

It should be noted though that a superposition state does not describe a vase that would possess the properties of solidity and fragility, absurdly, at the same time. It is simply a state in which both properties of solidity and fragility are *available to be actualized during an observational experiment*. This means that these two properties are not possessed by the vase in the *actual* sense of the term, but only in a *potential* sense, as they can be created (actualized) by the very process of their observation.

What we are illustrating here, by means of this simple and anecdotal example, is what *Claude Bernard* (the father of scientific physiology) used to call the *absolute principle of the experimental method* (Bernard, 1949), affirming that if an experiment, when repeated many times, gives different results, then the associated experimental conditions must have been different each time.[1]

When confronted with the quantum measurement problem, because of their classical training, physicists were initially brought to assume that what could vary in the experimental conditions was the initial state of the physical entity, and that by taking its variability into account it would be possible to explain the emergence of quantum probabilities. This assumption is quite natural if one thinks that a measurement process should just be a process of discovery of properties pre-existing the act of measurement, and not, possibly also, a process of creation of those same properties that are measured.

The hypothesis that it was the initial state of the system that was not controllable and could therefore fluctuate when a quantum measurement was performed, gave birth to the so-called *hidden-variable theories*, of which *Albert Einstein* was one of the most famous proponents. These theories, however, went out to meet considerable difficulties, expressed by the so-called *no-go theorems* (impossibility proofs, an example of which are the famous *Bell's inequalities*). These theorems have shown unequivocally that the attribution of

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[1] This is a reversed, alternative way, to state the *principle of determinism*, affirming that if everything is given in an experiment, then there are no known reasons to think that the result of the experimental process, if properly conducted, wouldn't be predetermined, whatever the outcome will be.

additional variables to the state of the system (called hidden-variables because they are not known and controlled by the experimenter) inevitably leads to the construction of a (so-called *Kolmogorovian*) classical probability model. It is important to note, however, that the *Hilbertian* probabilistic model of quantum physics is very different, from a structural point of view, from a classical probability model (in the same way as, for example, the geometry of the relativistic space-time is structurally very different from the Euclidean geometry).

On the other hand, if the hidden-variables are attributed not to the state of the system, i.e., to its wave function, but rather to the interaction between the measured entity and the measuring system, then the no-go theorems no longer apply, and this explains why the hidden-measurement interpretation is able to not only conceptually explain the nature of a quantum measurement process, but also to mathematically derive, in a non-circular way, the Born rule, which characterizes the probabilistic model of quantum mechanics (Aerts & Sassoli de Bianchi, 2014).

Of course, much more should be added about the effectiveness of the hidden-measurement interpretation, not only in solving the central measurement problem but also in shedding light on many of the mysteries of quantum physics. But doing so would require the space of an entire book, as well as the discussion of many technical details. What we want to stress here is that if we agree to take quantum physics seriously, that is, if we accept the challenge with which this theory confronts us, without seeking an easy way out, we can access new and more advanced explanations about the behavior of the physical entities in relation to the processes we use in order to observe/measure them. These more advanced explanations, in turn, allow us to open much wider windows to the genuinely multidimensional nature of our physical reality.

6 Non-spatiality

In the previous sections we have tried to explain what it means to take quantum physics seriously in relation to its central measurement problem. We have also tried to illustrate, by means of a very simple example, some of the foundational concepts of the hidden-measurement interpretation, whose distinctive characteristic is precisely that of taking full consideration of the collapse of the wave function, explaining it as a perfectly objective physical process resulting from the presence of fluctuations in the interaction between the entity subjected to the measurement and the measuring system.

Among the remarkable consequences of this approach, there is the fact that a quantum measurement process should be generally understood as a process that not only contains aspects of *discovery*, but also aspects of *creation*.[2] However, these processes of creation have nothing to do with the action of a vaguely defined non-physical consciousness through an equally vaguely defined psychophysical mechanism, but are the consequence of the interaction between the macroscopic system corresponding to the measurement apparatus and the (usually microscopic) entity submitted to its action.

By taking seriously the measurement process, the hidden-measurement interpretation takes also very seriously the wave function describing the state of the system. When the wave function of a quantum entity, such as an electron, is in a state of superposition, for example of superposition between two states localized in two separate and distant regions of space, such a state cannot be understood as the description of a condition in which the electron would be simultaneously in two different places (without being present in the intermediate region); nor can it be understood as a state describing a subjective condition of lack of knowledge regarding the actual location of the electron.

As the example of the vase illustrates, an electron in a superposition state of this kind is not present in either of these two places, as it does not possess a specific position in the three-dimensional space; it is just *available to be localized in one of these two regions in the course of an experiment of observation-creation of a position*. In other words, superposition states, here considered in relation to the *position observable*, are to be understood as *non-spatial* states, of pure *potentiality*,

[2] Measurements maximizing the discovery aspect are the so-called *classical* ones. Those maximizing the creation aspect are called, in a metaphorical sense, *solipsistic*. Quantum measurements realize a sort of optimal equilibrium between these two aspects, which makes them particularly *robust* in statistical terms (Aerts & Sassoli de Bianchi, 2015a,b).

not characterizable by a predetermined localization in the three-dimensional physical space, in the same way the superposition states of the vase are not characterizable by a predetermined condition of solidity or fragility. To quote the words of Diederik Aerts, we are then forced to give evidence to the fact that (Aerts, 1999):

"Reality is not contained within space. Space is a momentaneous crystallization of a theatre for reality where the motions and interactions of the macroscopic material and energetic entities take place. But other entities – like quantum entities for example – "take place" outside space, or – and this would be another way of saying the same thing – within a space that is not the three-dimensional Euclidean space."

Hence, quantum mechanics, if taken seriously, tells us that our physical reality is more extensive, dimensionally speaking, than what we are led to believe based on our ordinary experience, obtained through our physical body and its macroscopic interactions with other macroscopic physical entities. This three-dimensional theater of ours emerges from some underlying "theaters" of much higher dimensionality in which the microscopic entities, when they do not form macroscopic aggregates or interact with other macroscopic entities, reside for most of their existence (see Figure 5).

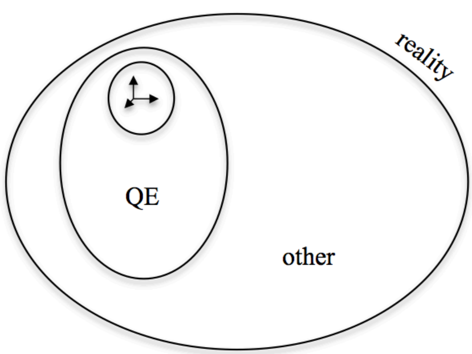

Figure 5 A symbolic representation of our reality (in the form of a Venn diagram), with the three-dimensional physical space (symbolized by the three Cartesian axes) emerging from an ampler non-classical reality, of higher (perhaps infinite) dimensionality, called the *quantum extraphysical* (QE) reality.

To think of the quantum superposition states as just *non-spatial* states remains however a rather approximate description. Indeed, it is possible to define superposition states in relation to any physical observable and not only in relation to the position observable. For example, we can superpose states of different momentum, energy, angular momentum, spin, etc., and all these superpositions continue to describe possible physical conditions that a physical entity is able to be in. Therefore, the term "non-spatial," when referring to a quantum microscopic entity, is to be understood not only in relation to the space of positions, but also in relation to "spaces" of speed, momentum, energy, angular moment, spin, etc.

The existence of (non-spatial) quantum superposition states reveals an unexpected nature of the microscopic quantum entities, in no way comparable to that of the objects of our ordinary intraphysical experience. How can we understand this nature? We will discuss this in the last sections of this article, as for the moment we must deal with the second field of investigation that, from our viewpoint, also needs to be taken more seriously by the international community of researchers: the study of consciousness.

7 Taking consciousness seriously

We now want to explain what we mean by taking seriously the study of consciousness. Of course, as is the case for quantum physics, the study of consciousness is an extremely vast and complex field of investigation, involving a number of questions not only related to the phenomenon of consciousness as such, but also to the functioning of the human mind in general, and its specific relation to the cerebral organ.

Following *Huxley* (1959), we can say that humankind corresponds to that particular stage of evolution when evolution becomes conscious of itself; and of course, when that happens, it starts questioning itself about its nature and condition. In the ambit of the modern study of consciousness, it is usual to consider that the so-called *hard problem* is about explaining the how and why of our subjective experiences, i.e., the ability of humans (and possibly, in different degrees, of other living beings) to be aware of our perceptions and of our very existence.

This is undoubtedly a fundamental issue. Why some *entities* are also *subjects*, that is, entities capable of consciously living their own experiences? Some could argue that the human consciousness is overrated, as our behaviors and thoughts are much more robotic, reactive and predictable than we are usually willing to accept, as emphasized by the Armenian philosopher and mystic *Georges Ivanovič Gurdjieff* (Ouspensky, 1949). On the other hand, regardless of the condition of "consciential sleep" in which we humans, undoubtedly, very often find ourselves, it is true that on some occasions of our life we can affirm, with reasonable certainty, that we are consciously aware of what we are experiencing and feeling at that particular moment, so much so that our awareness can become the trigger of an interrogation, for example about why we do what we do, if it is right to do it, or about why we are not able to do what we would like to do; eventually considering even deeper interrogations about the general sense of our existence and the nature of our inner being; interrogations that some people have the intelligence to then turn into a real theoretico-practical journey of self-research.

Now, the problem of consciousness, understood here as the possibility of explaining the origin of our introspective and conscious perceptive phenomena, as well as of our decision making and thought processes, can be treated either as an ordinary problem, in the sense of a problem which is in principle solvable within the paradigm of our classical spatiotemporal vision of reality, or as a problem of a purely metaphysical nature, totally unsolvable, the difficulty of which would be equal to that of the problem of the existence and characterization of what is commonly indicated by the word "God."

In the first case, we can quote the emblematic example of an author like *Douglas Hofstadter* (2007), according to whom the problem of the definition and understanding of what a consciousness is, that is, what a self-conscious subject is, would reduce, in the final analysis, to the possibility of identifying and characterizing specific *self-referential structures* in our brain. In other words, it would be the existence of specific *loops* in our brain that would confer us the ability of being self-conscious and self-aware.

The purely materialistic vision of Hofstadter, supported by philosophers such as *Daniel Dennett* (2005), can be contrasted by the view of many spiritual traditions of this planet, such as for example that of the *Vedic* doctrines of the *Upanishads*, stating that behind the manifestation of the individual consciousness there would be nothing but the very divine principle (*Brahman*). Therefore, understanding the nature and origin of consciousness would be equivalent to understanding the nature and origin of God, regardless of how we want to understand such an ineffable concept. It follows that the hard problem of consciousness would not be so much a hard problem, but an impossible problem, in the sense that it would be a problem we humans can only solve when (and if), in the ambit of our consciential evolution, we would be able to fully realize our deepest and most hidden nature and the ultimate meaning of our existence.

Without diminishing the importance of the study of consciousness from a purely brain-centric perspective, that is, from the viewpoint of its neural correlates (the so-called *easy problem of consciousness*) and of the possible self-referential structure of some of its circuitry, and without diminishing the importance of a purely philosophico-metaphysical reflection about the nature of being and consciousness, and its relation to that whole (in part manifest and in part unmanifest) associated with the concept of God, it is important to emphasize the possibility and usefulness of adopting an intermediary approach to the problem, a sort of "middle way" between physics and metaphysics: an approach which, from our perspective, is precisely about taking seriously the study of consciousness.

The starting point of this approach is the acknowledgment of the existence of many phenomena related to the manifestation of the consciousness the explanation of which is still highly problematic for those who adopt the limited perspective of *physicalism*, but also for those who, to such a perspective, only oppose a philosophical reflection on the nature of the separation between the sensible and the supersensible, where the latter is understood as a reality that, by definition, cannot be known in our present intraphysical condition.

We are referring here to the so-called *psychic* (or *parapsychic*) *phenomena*, studied in particular by the *parapsychologists*, and sometimes also referred to as paranormal phenomena, or anomalous phenomena. Among these, we may mention the category of so-called *extra-sensory perceptions* (ESP), which includes, for example, *telepathy*, *clairvoyance*, *precognition* and *retrocognition*; the category of *psychokinetic phenomena* (PK), which includes the *actions at a distance* on physical objects and "subtle" *healings*; and finally the cross category of *extracorporeal phenomena*, which includes the *near-death experiences* (NDE), the lucid *out-of-body-experiences* (OBE) and the *cosmoconsciousness* (non-dual) experiences.

These phenomena can be considered to be *extra*ordinary in the sense that it does not seem possible to explain them by remaining within the confines of a purely classical and three-dimensional view of our reality, in the same way as it is not possible to explain the quantum phenomena supposing that everything we observe would only take place in our specific spatial theater.

In other terms, we think that in addition to the easy and hard problems of consciousness (as defined by Chalmers), a *serious problem of consciousness* should also be considered, which is precisely about the identification of *physical and extraphysical models and mechanisms able to explain the parapsychic phenomena related to the manifestation of the consciousness*, the explanation of which remains highly problematic for those who adopt the limited perspective of physicalism.

The problem is "serious" for two reasons: because it is a difficult problem, whose solution will probably require a scientific revolution, and because it demands taking seriously the full spectrum of phenomena related to the manifestation of the consciousness.

8 Telepathy and non-spatiality

Let us consider as an example the phenomenon of *telepathy*. As the reader is probably aware, the evidences about extrasensory perception (ESP) phenomena (as well as psychokinesis) are still considered to be insufficient by the majority of the scientific community. In the sense that it is believed, erroneously from the viewpoint of this writer, that the data so far collected is principally the result of an incorrect evaluation, and therefore not significant enough in stressing the objectivity of the ESPs.

Unfortunately, this is an opinion mostly shared by scholars who generally operate outside this field of investigation, usually possessing very little knowledge about the value of the data that has been collected so far, in more than a century of parapsychological research. In other words, the dominant opinion of the scientific community does not seem to be always the result of a well-documented and reasoned knowledge, but more of a historical prejudice.

There is also a considerable dissonance between what many scientists declare officially, when questioned on this controversial topic, and what they sometimes say in private, about their real beliefs (as the author has been able to ascertain on some occasions). This is because in the academics parapsychism remains a taboo, with the result that the parapsychological research is still today marginalized and the opinion of the true experts called a priori into question.

Being that it is not the purpose of this article to go into the merits of these issues, we refer the interested reader to the many reference texts on the subject, in which enough information can be found about the extent of the laboratory research that has been carried out to date; for example: (Irwin & Watt, 2007; Krippner & Friedman, 2010; Parker & Brusewitz, 2003; Radin, 1997; Vieira, 2002). Particularly useful is the list of references recently selected by *Dean Radin*, which can be downloaded from the website of this researcher, who rightly writes:[3]

"*Commonly repeated critiques about psi, such as 'these phenomena are impossible,' or 'there's no valid scientific evidence,' or 'the results are all due to fraud,' have been soundly rejected for many decades. Such critiques persist due to ignorance of the relevant literature and to entrenched, incorrect beliefs. Legitimate debates today no longer focus on existential questions but on development of adequate theoretical explanations, advancements in methodology, the 'source' of psi, and issues about effect size heterogeneity and robustness of replication.*"

Let us consider the phenomenon of telepathy, which has been corroborated by numerous laboratory experiments and countless anecdotal evidences (personal experiences). It points out the possibility for an individual A, separated and isolated from another individual B, to *mentally connect* with B, in order to transfer some information about a given entity (such as a photo that A may have chosen in a non-predetermined way from a set of photos), so that B can subsequently identify, in a statistically significant way, the received information (for example by recognizing the transmitted picture among the set of photos in question).

This means that, despite the spatial separation and the physical

[3] www.deanradin.com/evidence/evidence.htm.

isolation, that do not allow A and B to communicate via ordinary channels of communication, a "subtle" form of communication takes place between A and B, i.e., a transfer of information through a *non-ordinary communication channel.* Therefore, if we take seriously the experimental data of telepathy, and do not want to renounce explaining them in an intelligible way, we are forced to appeal, similarly to quantum physics, to the notion of *non-spatiality*.

Of course, we might be tempted to speculate that telepathic communication may occur along an ordinary communication channel, of a spatial nature, as is the case with other known forms of communication, and that this channel would simply be associated with fields of force and/or matter-energy which are still unknown to us. Logically speaking, this is obviously a possibility that we cannot completely exclude; however, it faces many difficulties. In fact, if we assume, as is the case in the current dominant scientific paradigm, that a human being is nothing more than a very complex physical object, necessarily it will obey the same laws as every other three-dimensional macroscopic physical entity. Therefore, these hypothetical fields of force and/or matter-energy, carrying the telepathic communication, should have long since been observed in the general study of physical systems.

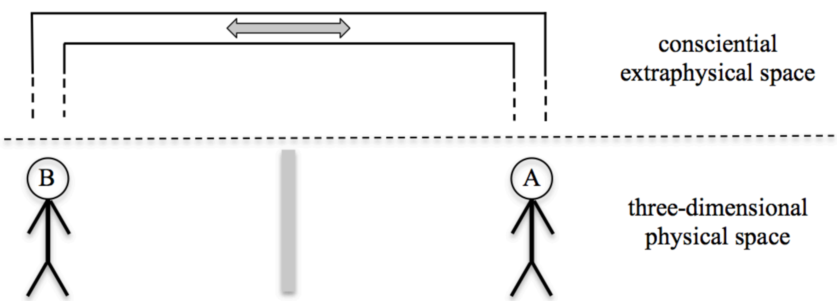

Figure 6 A symbolic representation of the non-spatial (extraphysical) telepathic communication channel, which allows two subjects, A and B, spatially separated and physically isolated, to exchange information.

Naturally, one could argue that these fields would interact in an extremely weak way with the ordinary matter, as is the case for example of the *neutrinos*, associated with the so-called *weak nuclear force*, and that this would explain why they have not yet been detected experimentally. But if so, how can we reconcile the weakness of their interaction with the possibility of a statistically significant telepathic communication?

For example, to capture one neutrino out of two, coming from a source such as the sun, we should have a physical body made of lead 10,000 billion kilometers thick. Therefore, a communication based on the neutrinic field would be infinitely too inefficient to be able to account for the possibility of telepathy, and the same argument applies, *mutatis mutandis*, to those other possible physical fields still unknown to us, having an extremely weak interactivity with ordinary matter, in standard conditions.

It therefore seems rather unlikely that telepathic communication could take place through ordinary channels of communication within our spatial theater. So, if we take seriously the phenomenon of telepathy, the only convincing explanation is that it occurs through a "mental layer" of our reality, of a non-spatial nature, and that this mental layer would be in relation to the mental activity of us humans (and of all other living creatures having mental abilities).

We would like to emphasize that we are not saying here, as one can often read, that human beings would be equipped with an *extended mind*, in the sense of a mind that would act similarly to a *field*, as a field remains a spatial entity, although of an extended nature. An electromagnetic field, for example, is an entity that can spread in space and whose perturbations do propagate in space;[4] therefore, they cannot be used to establish a communication between two spatially separated entities, for example when isolated in special Faraday cages.

9 OBE and non-spatiality

Following the above brief excursus on the phenomenon of telepathy, we want now to consider another typical phenomenon of the

[4] This is the case only when considering an electromagnetic field of the classical kind, and not the individual quanta of this field, the so-called *photons*. These are in fact non-spatial entities that cannot be associated with a specific spatial trajectory. On the other hand, while propagating outside of space, they remain in a close relationship with it, as it is always possible to absorb them by means of specific spatial detection instruments.

manifestation of the consciousness: that of the *extracorporeal states*. As is the case with telepathy, if taken seriously, the available data about *near-death experiences* (NDE), and more generally about *out-of-body experiences* (OBE), lead us once again to hypothesize the existence of a non-spatial "layer" of our reality.

As is the case with ESP phenomena, also regarding the objectivity of OBE and NDE (NDE are just a specific category of OBE caused by traumatic events) the majority of the scientific community remains deeply skeptical, as well as deeply unprepared. Let us be clear, the phenomenon as such, and its spread within the human population, is certainly not denied; it is acknowledged that about 5% of the population has had the opportunity to experience at least once an OBE (Blackmore, 1982; Irwin, 1985). However, it is often reduced to a mere *autoscopic hallucination* produced by the brain, when exposed to certain stimuli, internal or external (Aspell & Blanke, 2009).

Typically, in psychological and neurological ambits, an OBE is characterized in terms of the following three phenomenological elements (Irwin, 1985; Blanke *et al.*, 2004): the impression

(a) that the self is localized outside one's own body;
(b) of seeing the world from an extracorporeal and elevated perspective;
(c) of seeing one's own body from this perspective.

Now, for those researchers promoting a participatory investigation conducted also, and above all, by means of a first person experimentation (self-research), as is the case for instance within *International Academy of Consciousness*, and in similar organizations, it is clear that the above three impressions represent only a caricature of what a lucid projector with sufficient expertise of the projective phenomenon is able to experience (Muldoon & Carrington, 1929; Monroe, 1977; Buhlman, 1996; Bruce, 1999; Vieira, 1997, 2002; Ross, 2010; Aardema, 2012; Minero, 2012).

An OBE, lived in a lucid and self-conscious way, involves energetic phenomena, which sometimes can be very intense, like *vibrational states* and *intracranial sounds*, typically during the take off and the reentry into the body; it also often involves a superior mental activity, if compared to that of our normal intraphysical waking state; the observation and participation in events which are not only physical but also extraphysical, that is, taking place on other "planes" of existence, relatively stable and independent from the intrapsychic activity of the projector; events which occur in a logical and coherent way, also involving meetings and exchanges of relevant information with extraphysical (disembodied) consciousnesses, of different evolutionary levels, often also including departed family members (Vieira, 1997, 2002; Fenwick, 2012).

During a lucid OBE we can also experience the crossing of interdimensional passages separating different planes of manifestation and have access to panoramic visions of our intraphysical lives, to meaningful retrocognitions of past intraphysical lives, or of the periods of preparation between them (*intermissive periods*). To this we can add the fact that people who are blind from birth are sometimes able to see when they are in an extracorporeal state, and that numerous cases of confirmed *veridical perceptions* exist (Holden *et al.*, 2009), namely, of perceptions that the consciousness can have when outside of the body that the physical body cannot have access to, which subsequently find confirmation, including experiences of shared projections. Finally, to complete this partial list of features, it is important to observe that in the case of particularly meaningful OBE (especially the NDE), they are able to promote very deep and positive transformations in the lives of the subjects, like the acquisition of a more advanced ethical sense and increased psychic abilities (which are often experienced in an amplified way when in the extracorporeal condition).

What we want to emphasize here is that the most significant aspects of an OBE are not usually taken into account in the academic study of the phenomenon, especially the fact that these experiences are very different from the ordinary dream activity (Vieira, 2002) and often involve the exploration of existential dimensions by using extraphysical vehicles of manifestation (see Figure 7) that are difficult to explain only as vivid hallucinations. One just has to read the diary of the OBEs of a veteran projector like Waldo Vieira (1997) to understand that the oneiric-hallucinatory "explanation" completely lacks *explanatory power*.

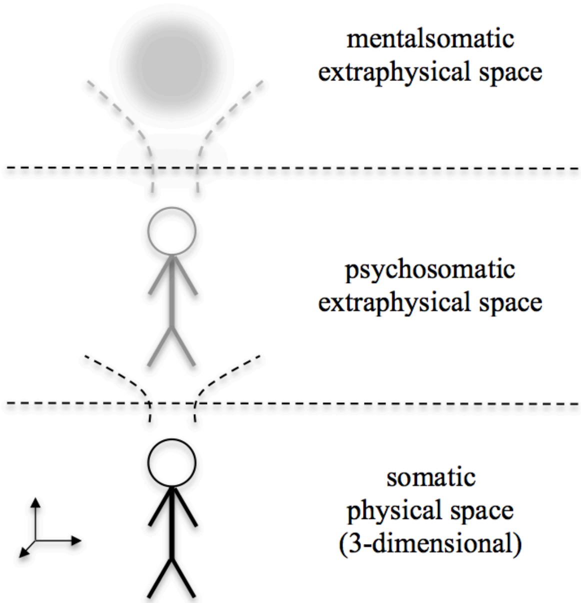

Figure 7 A symbolic representation of the (somatic) 3-dimensional physical space, symbolized by the 3 Cartesian axes, and of the consciential extraphysical (CE) "spaces" (psychosomatic and mentalsomatic) that a projected consciousness is able to experience in the course of so-called psychosomatic and mentalsomatic projections, respectively, by using corresponding extraphysical vehicles of manifestation. In the drawing, the dashed funnels represent the effect of "consciential narrowing" which is typically experienced when the consciousness moves from "subtler" to "denser" dimensions.

Certainly, its advantage is that it doesn't require the introduction of new entities, in obedience to the famous *Ockham's razor principle*. On the other hand, if it is true that Ockham's razor reminds us, rightly, not to introduce more entities than necessary, it is also true that it should always be carefully counterbalanced by the so-called *Chatton's anti-razor principle*, which warns us of the opposite danger, that of becoming too economical and introduce less entities than necessary (Smaling, 2005). What really matters is not the number of entities that we introduce in our theories, but if our theories possess sufficient explanatory power to explain the different observed phenomena, be them internal or external.

As an example, take the case of physicist *Wolfgang Pauli*, who in 1930, with courage, was brought to postulate the existence of a new ghost-like microscopic entity, later on called *neutrino* by the Italian physicist *Enrico Fermi*. For this, he had to "disobey" the dictates of Ockham's principle, and if he did so it was to *explain* in an understandable way the phenomenon of *beta decay*. Similarly, when considering the phenomenon of OBE, if we decide to take it seriously, i.e., to take into account the entire spectrum of its distinctive features, it is undoubtedly necessary to hypothesize the existence of extraphysical existential dimensions and of objective vehicles of manifestation used by the consciousness to travel through them. To quote *Waldo Vieira* (2002):

"*It is the most adequate hypothesis for explaining a greater series of consciential phenomena (phenomenology) which are currently considered to be parapsychic.*"

Of course, there are a number of reasons, having little to do with the logic of scientific inquiry, which explain why this assumption is not at the moment taken seriously by the scientific community at large. Some of these have to do with historical prejudices, and the need for a science, still adolescent and insecure (*adole-science*), to distance itself from those fundamental interrogatives that gave birth to the various religious movements; interrogatives that are judged a priori as unscientific, like for example: Who and what am I? Where do I come from and where am I going? Is there something beyond the physical death? What is my potential for evolution and how can I actualize it? (Sassoli de Bianchi, 2012b).

To this we must add the difficulty, on the part of the modern scientific enterprise, to integrate in its corpus of knowledge the results of a participatory research conducted in the first and second person, recognizing the role that subjective experiences have, while also acknowledging that, inevitably, their reliability will vary depending on the training received by the individuals who live them.

But this is not the topic of this article. What we want to stress here, based on the evidences acquired from the research on telepathy and the extracorporeal states (but not only) is that these phenomena can be understood only to the extent that we courageously open ourselves to the possibility that a being-consciousness can also exist in *non-spatial* states, associated with extraphysical vehicles of manifestations and "places" which are perfectly objective, although located outside of the three-dimensional theater of our ordinary intraphysical experience.

10 Different typologies of non-spatiality

In the previous sections we have proposed the following thesis: if the study of microscopic entities and consciousness are taken seriously enough, we reach the conclusion that our ordinary physical reality is the tip of a huge extraphysical iceberg. However, at the present state of our knowledge, we cannot know if the non-spatiality of quantum microscopic entities, of projected (or departed) consciousnesses and of telepathic communication channels, correspond to the same extraphysical layer of our reality. This for the time being remains an open question.

To simplify the discussion, we will use the term *quantum extraphysical* (QE) to denote the non-ordinary space in which quantum entities are present for most of their time (when not forming macroscopic aggregates), and the term *consciential extraphysical* (CE) to refer to the non-ordinary space which is inhabited by the projected and departed consciousnesses, and which is possibly also at the origin of telepathic transmissions and other psychic phenomena.

The first logical possibility is that the QE and the CE "spaces" have nothing in common except the three-dimensional Euclidean theater, which has to be considered as a sort of meeting place for these two distinct layers of reality (see Figure 8).

Another possibility corresponds to the hypothesis, diametrically opposite, that the QE and CE "spaces" correspond to exactly the same reality layer. In other words, physicists, through their investigation of the micro-world, would have just put their hands on that "spiritual reality" that has been described by the mystics throughout all of time, as suggested for example by *Fritjof Capra* (1975) in his famous *Tao of Physics* (see Figure 9).

Between these two extremes, it is of course possible, and desirable, to consider the possibility of an intermediary perspective, according to which there would certainly be elements of reality that are shared by the QE and CE "spaces," but there would also exist purely quantum and purely consciential non-spatial layers that would have no common elements (see Figure 10).

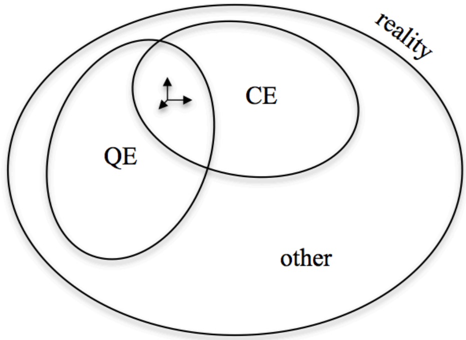

Figure 8 A symbolic representation of reality (in the form of a *Venn diagram*), with the three-dimensional physical space (symbolized by the three Cartesian axes) emerging from both the quantum extraphysical (QE) "space" and the consciential extraphysical (CE) "space," in the hypothesis that the multi-dimensional nature of these two layers would be distinct and therefore their intersection would be empty (in the sense of only corresponding to the ordinary three-dimensional space).

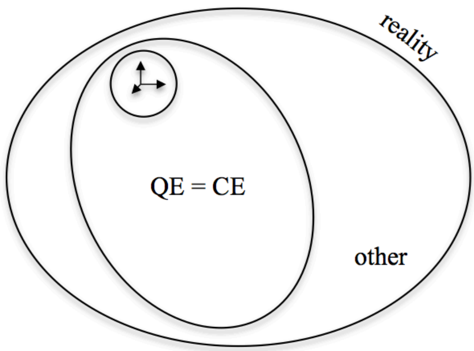

Figure 9 A symbolic representation of reality (in the form of a *Venn diagram*), with the three-dimensional physical space (symbolized by the three Cartesian axes) emerging from both the quantum and consciential extraphysical "spaces," in the hypothesis that they would coincide.

11 Entanglement does not explain telepathy

We will now present a few simple arguments to support the view that the QE layer can hardly be considered to be coincident with the CE one, as it is often assumed by many authors in the field of parapsychology, who see deep similarities between the psychic phenomena and the quantum phenomena, such as the *non-local* aspects which are present both in the extrasensory perception (ESP) phenomena, like telepathy, and in the coincidence EPR-like experiments (the abbreviation denotes the famous triumvirate Einstein-Podolsky-Rosen), performed on pairs of entities in *entangled* states (Aspect, 1999); or the fact that parapsychology and quantum experiments both use a *statistical approach*, and that the collapse of the wave function seems to imply the possibility of an active role played by the mind of the experimenter in actualizing the different possible outcomes of an experiment.

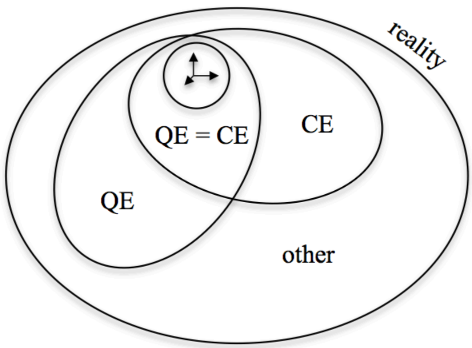

Figure 10 A symbolic representation of reality (in the form of a *Venn diagram*), with the three-dimensional physical space (symbolized by the three Cartesian axes) emerging from both the quantum extraphysical (QE) and the consciential extraphysical (CE) "spaces," in the hypothesis that they do not coincide and that their intersection does not only reduce to the three-dimensional physical space.

On the question of the *observer effect* (Sassoli de Bianchi, 2013c,f) we have already discussed it at length in the first part of this article. Until proven to the contrary, the observer effect of quantum mechanics only corresponds to an *effect of the instrument of the observer*. Therefore, this first element of correspondence between quantum measurements and ESP is only apparent.

As for the observation that both approaches abundantly use statistics, this similarity is also only apparent. Apart from the fact that any experimental investigation necessarily employs statistical methods, when it comes to analyzing the data obtained and the associated margins of error, it should be pointed out that the reasons for which quantum systems are described primarily in terms of probabilities is very different from the reasons why psi phenomena are evidenced by means of a statistical analysis.

Quantum probabilities are genuine *elements of reality*, in the Einstein sense of the term, as the values of the quantum probabilities, in the different experimental contexts, *can be predicted with certainty*. But not only that: the quantum statistics are characterized by an optimal *robustness* with respect to possible small variations of the state of the system (De Raedt et al., 2014; Aerts & Sassoli de Bianchi, 2015b). Also, quantum probabilities, associated with the different physical observables of a system, contain an objective and accurate information about the state of the system, which can be recovered using specific techniques of *quantum tomography*.

The situation is very different with regard to the data obtained in parapsychological experiments, characterized instead by a very weak replicability of the relative frequencies associated with the different possible outcomes. Moreover, the logic of the statistical analysis conducted in parapsychological experiments is very different from that of quantum experiments. In fact, considering the weakness of the psi effect in experiments conducted in a controlled environment, the purpose of the statistical analysis is to compare the data obtained in situations in which a supposedly non-ordinary ability would be at work, with theoretical data relating to situations in which this ability would be absent. To determine whether the difference between these two situations is significant, and therefore test the validity of the psi hypothesis, a probability is usually calculated (the so-called *p-value*), through various methods of statistical inference (Utts, 1991). This means that the statistical analysis of parapsychological experiments is of the *inferential* kind, and not of the *descriptive* kind, as it is the case for quantum statistical data.

Let us now consider the entanglement aspect. Here undoubtedly the similarity lies in the fact that, as already noted, both psi phenomena and those associated with the observations of microscopic quantum entities, if taken seriously, lead us to consider the existence of a *non-spatial* layer of reality. On the other hand, it is rare to read in the parapsychological literature the clear statement that quantum entanglement cannot be used as such, in no way, to transfer information from one subject to another (Sassoli de Bianchi, 2013g).

As an example, consider the well-known process of *quantum teleportation* (Bennet *et al.*, 1993). Without going into details, we can observe that this process corresponds precisely to the possibility of transferring information from one place to another (with the aim of duplicating a specific microscopic entity), using a non-ordinary, non-spatial channel, obtained by sharing a pair of entangled quantum entities. What is important to consider, in relation to our discussion, is that if it is true that such process of "teleportation" uses the phenomenon of quantum entanglement, it is equally true that the actual transport of information does not take place through the non-spatial channel, but through an additional and perfectly ordinary communication channel.

For this reason, the process is also known by the name of *entanglement-assisted teleportation*, which means that the entangled entities cannot be used to simulate, in no way, a telepathic-like communicational process. Entanglement can be used, in certain circumstances, to increase our communicational resources, when we are in the presence of an ordinary communication channel, but cannot be used as such to transfer information in the absence of the latter.

12 A simple example of entangled entities

As this is not an article aimed at an audience of only physicists, we think it is useful to explain, through a simple yet significant example, why an entangled entity cannot be used to transfer information from one place to another place. We will consider for this a model using a perfectly ordinary macroscopic entity: a *string*. The example takes its inspiration from a previous model designed by *Diederik Aerts*, known as the *connected vessels of water model* (Aerts, 1984; Aerts et al., 2000).

Since the eighties of the last century, Aerts has in fact shown that ordinary macroscopic systems are also able to violate the famous *Bell's inequalities*. These, as is known, are violated by entangled systems, that is, by systems that are not separated in experimental terms, despite being possibly separated in spatial terms. In the case of two microscopic entities, such as two electrons, or two photons, the non-separation is due to the presence of a non-spatial connection, whereas in the case of macroscopic systems the connection is of a spatial nature (i.e., is present in space). The crucial point in the violation of Bell's inequalities is not, however, if the connection is spatial or non-spatial, but if it is able to create correlations (Sassoli de Bianchi, 2013b).

Consider two colleagues, A and B, who hold the two ends of a stretched string, of length L. Suppose that the string is very long, so that between A and B there is a considerable distance, which does not allow them to communicate. The string, with its two ends, is the equivalent of a composite entity in an entangled state, shared by A and B. Suppose that A and B, in the same moment (in a coincident way), decide to pull with strength on their respective end of the string, causing it to break into two separated fragments. Accordingly, A and B will find themselves with a single string fragment in their hands. Suppose that L_A is the length of the fragment of A, and L_B is the length of the fragment of B. Since $L = L_A + L_B$, both A and B will be able to know the length of the fragment in the hand of their colleague, without having exchanged with the latter any kind of information (see Figure 11).

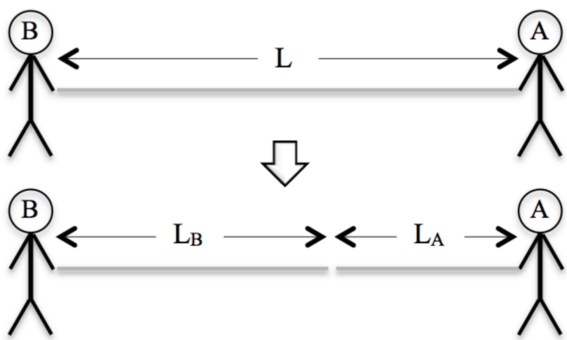

Figure 11 By pulling on the two ends of a string, a pair $(\boldsymbol{L_A}, \boldsymbol{L_B})$ of correlated values is created: $\boldsymbol{L_A} + \boldsymbol{L_B} = \boldsymbol{L}$. The experimenter A, by measuring the length $\boldsymbol{L_A}$ of its fragment, is thus in a position to know the length $\boldsymbol{L_B}$ in the hand of experimenter B, and vice versa, with no transfer of information.

We can observe that: (1) the two *potential string fragments* (forming the entangled entity) acquire a specific length only following the breaking-measurement process (in the same way as the spins of an entangled pair of electrons acquire a specific orientation only following a Stern-Gerlach measurement process). In other words, it is the measurement process which creates the properties; (2) the lengths acquired by the two fragments are perfectly correlated (as perfectly correlated are the orientations of the electronic spins); (3) the process does not correspond to a discovery of already existing correlations, but of creation of correlations that were only potential prior to the experiment (called *correlations of the second kind* by Aerts); (4) it is the process of creation of correlations that is responsible for the violation of Bell's inequalities (Sassoli de Bianchi, 2013b,d, 2015a); (5) since the breaking point of the string cannot be controlled by A and B, they cannot use the obtained pair of values $(\boldsymbol{L_A}, \boldsymbol{L_B})$, which are correlated but arbitrary, to transfer information from A to B, or from B to A.

Point (5) is the crucial one. Indeed, the situation of quantum entanglement is structurally similar to that of the string. The string is a *spatial* entity, which connects couples of potential fragments through space, whereas a pair of entangled electrons (or photons) is a *non-spatial* entity, which connects pairs of potential orientations *not* through space. But in both cases, the fundamental process is that of a genuinely indeterministic *creation of correlations*, and this process *cannot be used to communicate*.[5]

13 Differences and similarities between QE and CE

Let us consider now the consciential extraphysical (CE) reality that we consciousnesses can have access to during an extracorporeal

[5] More precisely, this is so because the quantum probabilities obey the so-called *no-signalling conditions*, also called *marginal laws*. On the other hand, some experiments have also indicated that these marginal laws could possibly be violated (as it is in fact the case for the model using the string, if additional experiments are considered). Hence, a communication which directly exploits the entanglement phenomenon may after all be possible, although not at superluminal effective speed. For a discussion of these subtle questions regarding the quantum formalism and the interpretation of quantum entanglement, see Aerts et al (2019) and the references cited therein.

projection, assuming that such non-spatial reality, and the vehicles we use to manifest in it, are perfectly objective. As for the phenomenon of telepathy, the question is then the following: *Do we have elements to support the view that the quantum extraphysical (QE) and the consciential extraphysical (CE) would form the same layer of our reality?*

It is certainly a difficult question, since we do not know yet the "physics" that governs the CE layer. However, we can observe that there are aspects of it that are both in favor and against the thesis that it would be an expression of a quantum reality. For example, an extraphysical consciousness, manifesting through the "subtle" vehicle called *psychosoma* (Vieira, 2002), will experience the equivalent of a 3-dimensional spatial scenery, in which it will be able to move along well-defined trajectories. On the other hand, it is equally true that the psychosoma can also teleport itself from one place to another, without apparently passing through the intermediate regions, like an entity able to de-spatialize at will.

In the CE layer, we can also observe the presence of objects with specific and stable individual characteristics, which can interact according to classical modalities (such as falling, or bouncing), without entering into conditions of entanglement, as well as the presence of "objects" which, instead, are able to easily vary their appearance, size, fuse with one another, establish invisible connections, etc., contrary to what the intraphysical macroscopic objects are usually able to do.

There is also a portion of the CE layer that is undoubtedly much more "abstract," where the consciousness seems to be able to manifest through an even subtler vehicle than the psychosoma, not characterizable anymore as a body having spatial-like characteristics, called the *mentalsoma*. To try to convey the idea of the possible nature of this mentalsomatic consciential reality, we leave the word to *Waldo Vieira*, who in his diary describes an experience of mentalsomatic projection (Vieira, 1997):

"*[...] I saw only lights and vivid colors of indefinite shapes. The site appeared to be completely uninhabited. There were no dwellings in sight. My experience was that of simply existing as a consciousness. I did not feel the form of the psychosoma. It was invisible even to me.*

Lighter than usual outside the dense body, I had an attitude of confidence and moral superiority, which made unequivocally sublime energies arise within me, *in an indefinable, tranquil contentment. There were no human forms or faces, only centers of energy radiation constituting familiar consciousnesses, some of which were noteworthy [...].*

They had no names, nor were they identifiable by their forms, but I knew them and was united with them through common experiences. I was suddenly sure of being a participant in a formless gathering, composed of bodiless points of mental focus, of masses of energy that was taking place in a nirvanic atmosphere that was of an unimaginable level of mental elevation, unapproachable with Earthly descriptions, and indefinable in known terms."

So, if we take seriously what the lucid projectors report, we can observe in the CE "space" the presence of entities (including the consciousnesses' vehicles of manifestation) whose behavior is seemingly classical, but also of entities whose behavior is decidedly quantum-like. This suggests that the CE layer would not be equivalent to the QE layer discovered by physics, but would correspond to a reality hosting inside of it a consciential classical-like level, of a spatial-like nature (different from the ordinary intraphysical space), and a quantum-like consciential level, of a non-spatial nature (different from the quantum non-spatial layer studied by physics); see Figure 12.

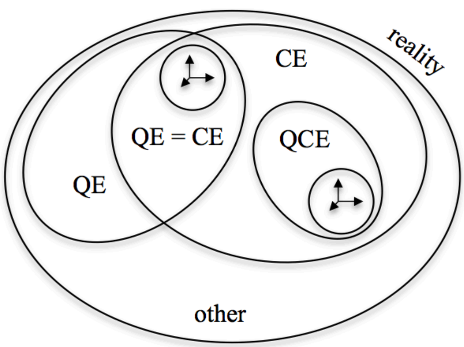

Figure 12 A symbolic representation of reality (in the form of a *Venn diagram*), containing the three-dimensional physical space (symbolized by the three Cartesian axes) and the quantum extraphysical (QE) and consciential extraphysical (CE) "spaces," in the hypothesis that they do not coincide, that their intersection does not reduce to the three-dimensional physical space, and that the CE layer also contains a quantum-like level (QCE), distinct from the QE, as well as a classical-like level (symbolized by the three Cartesian axes).

14 Quantum cognition

From what has been discussed in the previous sections, a picture of a very multifaceted multidimensional reality emerges, in which the QE and CE layers appear to be possibly distinct and not easily comparable. In this sense, we believe that the modern researcher/self-researcher has an interest in resisting the temptation to prematurely produce all too easy simplifications, as the one of considering, based on vague and unconvincing analogies, that the microscopic layer described by quantum physics would be in direct correspondence with the non-ordinary reality associated with the psi phenomena, and more generally to the more complex parapsychic experiences such as the OBEs.

To use a metaphor, we can imagine being in a house, where we were born; a house that we have never left. Getting close to a window, we open it, and through that window we see a strange and wonderful landscape. Suppose that it is the window of quantum physics. Then, we open another window, which is oriented in a different direction, and also in this case we see a landscape, also strange and wonderful. Suppose that it is the window of parapsychic experiences. Since both of these landscapes appear to us strange and wonderful, we will be tempted to believe that the two windows open on the same landscape, on the same reality. The temptation will be further strengthened by the fact that both windows belong to the same three-dimensional house. But this is obviously not sufficient. For example, if the house is located on the seashore, one window might look inland, the other one to the open ocean. And if we lived for a very long time imprisoned in that house, both of these landscapes will appear to us strange and wonderful; but their reality will remain very different: one is inhabited by fishes, the other one by quadrupeds.

Of course, we can always imagine a more fundamental level, where the inland and the sea will appear to us as part of a larger undivided reality, but here we leave the metaphor. Indeed, it is always possible to conceive a more fundamental level, but at the present state of our knowledge we have no reason to think that our parapsychic experiences, and our quantum experiments, would have been able to even scratch such level.

Having highlighted in the previous sections some of the differences between the fields of investigation of *quantum physics* and *consciousness*, when both are taken seriously, we want now to indicate what they possibly have in common. But to do so, we first need to mention a recent small revolution that has taken place in the study of human cognition and the correspondent decision processes: that of so-called *quantum cognition* (Busemeyer & Bruza, 2012), not to be confused with the theory of the "quantum brain," which we mentioned in the beginning of this article.

Similarly to how physicists, in the course of their historical investigations, were confronted with experimental data which were incompatible with classical probabilities, psychologists (here primarily understood as cognitive scientists) were also confronted with empirical data (collected in the ambit of tests conducted on statistically significant samples of subjects) that appeared to be completely irrational if analyzed according to classical logic, in the sense of being the expression of evident "logical errors," such as the *conjunction fallacy* (a condition in which subjects estimate that the probability that two events occur in conjunction is greater than the probability that only one of the events occurs) or the *disjunction fallacy* (a condition in which an alternative is considered less likely than an absence of alternative).

From these and other anomalies, evidenced in numerous experimental studies, it could be inferred that human thought processes do not always follow classical logic. Historically, these deviations were mostly considered to be the expression of purely associative and irrational processes, with no detectable structure; at least until it was thought of to apply some specific quantum mathematical models in the attempt to account for these deviations. In this way, a specific and identifiable structure in the alleged human irrationality could be observed, as an expression of a *quantum-conceptual* layer in our thought processes, of a *synthetic* nature, which has to be added to the *logico-classical* layer, of an *analytical* nature, usually (and erroneously) taken for granted (Aerts & D'Hooghe, 2009).

This quantum conceptual thought process is highly *contextual* and *indeterministic*, although not arbitrary, similarly to the measurement processes on microscopic quantum entities. In fact, like the latter, the outcomes of the quantum-conceptual thought processes do occur, in those situations that are able to promote them, in a completely systematic, inter-subjective and stable way; in other words, they are not the result of accidental effects, but of effects whose statistics are very robust and replicable at will.

The application of quantum models to human cognition allowed the explanation of the deviations with respect to the classical probabilistic predictions in terms of the typical characteristics of quantum systems, such as *contextuality*, *emergence due to superposition*, *interferences*, *correlations due to entanglement*, not to mention the "many-body effects" specific of *quantum field theory*. It is obviously not possible to review all the details of these interesting modelizations, and the data that they allowed to elucidate, also because different approaches exist, depending on the authors, which model different aspects of the cognition and decision processes.

One of these approaches, perhaps the most fundamental one if we consider the ampleness and generality of the perspective it is able to offer, is that originally proposed by *Diederik Aerts*, *Jan Broekaert* and *Liane Gabora* (2000), and further developed in (Aerts & Gabora, 2005a,b, Aerts, 2009a). The idea of these authors is to model *human concepts* as entities that *can be in different states*, depending on the contexts, and not as mere containers of data (instantiations), i.e., as collections of predetermined exemplars.

15 Interferences between fruit and vegetable

As an example, consider the human concept *Fruit.*[6] When it is not in combination with other concepts, we can consider that the conceptual entity *Fruit* is in its *ground state*. But as soon as it is placed in a context, such as in the phrase *How juicy is this fruit*, its state will no

[6] We use a capital first letter and the italic style to denote concepts, which should be distinguished from the words that are used to indicate them.

longer be the ground state, but an *excited state*,[7] which will produce different effects compared to the ground state. Indeed, if for example we ask a person to choose a typical example for the concept in question, e.g., between the two possibilities *Apple* and *Orange*, there is no doubt that *Orange* will be chosen more frequently than *Apple* when the concept in question is in the *How juicy is this fruit* state, with respect to when it is in the more neutral *Fruit* ground state. It is important to note that also the exemplars *Apple* and *Orange* correspond to specific states of the conceptual entity *Fruit*, and more precisely to the states obtained by the following two contextualizations: *The fruit is an apple* and *The fruit is an orange*.

When a concept is contextualized, we can distinguish two fundamental types of processes: the *deterministic* ones, through which the concept is prepared in a predetermined state, and the *interrogative* ones, fundamentally *indeterministic*, through which the concept, prepared in a given state, is *measured* by means of an evaluation by a human subject (or by a group of human subjects), who is asked to choose a specific exemplar for the concept in question, from a given set of possible exemplars of the same. When concepts are measured in this way, the results obtained will generally obey non-classical (quantum-like) probabilities.

We will limit ourselves to one example, analyzed in (Aerts, 2010a,b), to explain what we mean by this last statement. Consider the concept *Fruit or vegetable*. It can be considered as either the conceptual entity *Fruit* in a specific state, or as a new conceptual entity, obtained by the combination of the two conceptual entities *Fruit* and *Vegetable*, by means of the logical connector *Or* (which in turn, of course, is also a conceptual entity). Imagine then submitting a set of specific exemplars to a group of subjects, asking them to do the following:

(A) choose from the set a typical exemplar of *Fruit*;
(B) choose from the set a typical exemplar of *Vegetable*;
(C) choose from the set a typical exemplar of *Fruit or vegetable*.

Suppose that the set in question contains the following 24 exemplars:

Almond, *Acorn*, *Peanut*, *Olive*, *Coconut*, *Raisin*, *Elderberry*, *Apple*, *Mustard*,

[7] Here the term "excited" is to be understood in the same way as it is used in quantum mechanics, to indicate a state that is different than the ground state.

Wheat, *Ginger root*, *Chili pepper*, *Garlic*, *Mushroom*, *Watercress*, *Lentils*, *Green pepper*, *Yam*, *Tomato*, *Pumpkin*, *Broccoli*, *Rice*, *Parsley*, *Black pepper*.

The different subjects will then choose these exemplars with different relative frequencies, in relation to the above three questions, and of course these frequencies can be interpreted as probabilities: the probabilities that a human subject, subjected to one of the above three situations, will choose those specific exemplars.

Let us consider the values obtained in a study by *Hampton* (1988). The probability that choice (A) gives the outcome *Mushroom* is:

$$P(\textit{Fruit} = \textit{Mushroom}) = 0.0140,$$

while the probability that choice (B) gives *Mushroom* is:

$$P(\textit{Vegetable} = \textit{Mushroom}) = 0.0545.$$

This means that the subjects consider mushrooms to be more representative of a vegetable than of a fruit, though in general they do not consider them to be very representative of either category, if for example we compare these values to the much higher probabilities:

$$P(\textit{Fruit} = \textit{Apple}) = 0.1184,$$

with which *Apple* is chosen as a typical exemplar of *Fruit*, or

$$P(\textit{Vegetable} = \textit{Broccoli}) = 0.1284,$$

with which *Broccoli* is chosen as a typical exemplar of *Vegetable*. Consider now the probability that *Mushroom* is chosen as a typical exemplar of the concept *Fruit or vegetable*. If we reason in classical terms, we would expect such probability, obtained by submitting the subjects to the choice (C), to simply correspond to the *arithmetic mean* of the values obtained in the two choices (A) and (B), namely:

$$\bar{P}(\textit{Fruit or vegetable} = \textit{Mushroom}) = \frac{1}{2}[P(\textit{Fruit} = \textit{Mushroom}) + P(\textit{Vegetable} = \textit{Mushroom})] = \frac{1}{2}(0.0140 + 0.0545) = 0.0342.$$

This would correspond to a process where the subjects first choose which of the two questions they want to answer, either question (A) or question (B), and after they have made such choice, they simply answer the selected question. Instead, the obtained experimental value was:

$$P(\textit{Fruit or vegetable} = \textit{Mushroom}) = 0.0604,$$

which is almost twice the value predicted by the above classical reasoning and corresponding arithmetic mean.

In the case of the exemplar *Mushroom* we therefore have an effect of *overextension* of the probability, with respect to the classical prediction. But effects of *underextension* are also observed. Consider for example the case of the exemplar *Elderberry*, whose experimental data are:

$$P(\textit{Fruit} = \textit{Elderberry}) = 0.1138,$$
$$P(\textit{Vegetable} = \textit{Elderberry}) = 0.0170,$$
$$P(\textit{Fruit or vegetable} = \textit{Elderberry}) = 0.0480.$$

The classical arithmetic mean produces in this case the value:

$$\bar{P}(\textit{Fruit or Vegetable} = \textit{Elderberry}) = \frac{1}{2}[P(\textit{Fruit} = \textit{Elderberry}) + P(\textit{Vegetable} = \textit{Elderberry})] = \frac{1}{2}(0.1138 + 0.0170) = 0.0654.$$

which is much greater than the obtained experimental value.

Following the reasoning in Aerts (2010a,b), to explain these deviations we can consider that a human subject, when assessing the typicality of an exemplar in relation to the concept *Fruit or vegetable*, will proceed according to a double modality: *logico-classical* and *quantum-conceptual*. The first modality consists of evaluating the typicality of the exemplar in relation to its components *Fruit* and *Vegetable*, taken separately, that is, decomposing the concept into its parts. This will produce essentially a value compatible with the formula of the arithmetic mean.

The second modality consists of considering *Fruit or vegetable* as a new *emergent* concept, that cannot be reduced, in regard to its meaning, to the meaning of its components taken individually. Therefore, in this second modality, the subject will try to evaluate if *Mushroom* is an exemplar which can easily be attributed, individually, to *Fruit* or to *Vegetable*, and if this is not the case, as for the exemplar *Mushroom*, it will be assigned to the new emergent concept *Fruit or vegetable*. In other words, it will receive a very significant score according to this second modality of evaluation, resulting in an effect of overextension with respect to the classical evaluation (which only considers the first modality).

The underextension effect observed in the probability of choosing *Elderberry* as a typical exemplar of *Fruit or vegetable* can be explained in the same way. In this case, however, and contrary to *Mushroom*, it is not an exemplar that is difficult to classify as *Fruit* or as *Vegetable*. Indeed, *Elderberry* is considered to be a typical exemplar of *Fruit*. Therefore, it will receive a negative score as regards to its assignment to the emergent *Fruit or vegetable* concept, thus producing a downward correction of the classical analytico-reductive evaluation (Aerts, 2010a,b).

When these effects of overextension and underextension of classical probabilities are analyzed using the (Hilbertian) formalism of quantum mechanics, they can be qualitatively and quantitatively explained as the result of *constructive* and *destructive interference effects*, respectively, exactly as it happens in a typical quantum experiment, when in the presence of interfering alternatives.

Take the example of the famous *Young's double-slit experiment* (that we assume the reader is familiar with). The situation (A) is equivalent to that where only "slit A" is open; the situation (B) is equivalent to that where only "slit B" is open; and the situation (C) is equivalent to that where both slits are open; on the other hand, the different exemplars that the subjects can choose are equivalent to the different possible locations on the final screen (in the present case, 24 locations) where the quantum entity can be finally detected (absorbed).

When the process is of the classical kind, that is, when the entities passing through the double-slit screen are corpuscles, the distribution of the impacts on the final screen obeys the laws of classical probabilities, in the sense that the probability that a particle reaches a certain position on the final screen, when both slits are open, is given by the *arithmetic mean* of the probabilities that it reaches such position when only one of the two slits is alternatively open.

On the other hand, if the process is quantum, the phenomenon of interference is able to produce variations in comparison to the predictions of a classical probability calculus; variations that will result in effects of overextension (constructive interference) and underextension (destructive interference), producing the typical *interference fringe pattern* on the final detection screen. And, surprisingly, similar fringes can also be obtained when measuring the concept *Fruit or vegetables*, as shown in Aerts (2010a,b).

16 The conceptuality interpretation of quantum physics

What we have described in the previous section is just an example of a significant experiment in cognitive science, able to highlight typical quantum-like effects, i.e., experimental data whose structure is very similar to that obtained in experiments with microscopic physical entities, in different experimental contexts. The reasons why quantum mathematics is so effective in the modeling of cognitive experiments are numerous and were analyzed for example in Aerts et al. (2013), Aerts & Sassoli de Bianchi (2015a,b); see also Busemeyer & Bruza (2012), and the references cited therein.

Now, considering the significant progress achieved in recent years in quantum cognition, we may be led to ask, together with Aerts, the following fascinating question (Aerts, 2010a):

If quantum mechanics as a formalism models human concepts so well, perhaps this indicates that quantum particles themselves are conceptual entities?

This question became the starting point in the development of a new interpretation of quantum mechanics, called the *conceptuality interpretation* (Aerts, 2009b, 2010a,b, 2013), which is perhaps today one of the most general and innovative explanatory frameworks to understand the "strange" behavior of the entities described by this theory. The assumption at its basis is the following (Aerts, 2010a):

Hypothesis NQE (nature of a quantum entity): The nature of a quantum entity is 'conceptual,' i.e., it interacts with a measuring apparatus (or with an entity made of ordinary matter) in an analogous way as a concept interacts with a human mind (or with an arbitrary memory structure sensitive to concepts).

In other words, according to *Hypothesis NQE*, the elementary microscopic entities, although not describable as particles, waves or fields, do nevertheless behave as things that are very familiar to all of us, as we continually experience them in a very intimate and direct way: *concepts*.

Of course, we cannot present here all the subtleties and complexities of the explanatory framework offered by this interpretation, and its effectiveness in explaining quantum phenomena such as entanglement and non-locality, which are traditionally considered to be "not understood" or "not understandable." We therefore leave to the reader the intellectual pleasure of discovering these explanations directly from the foundational work of Aerts (2009b, 2010a,b, 2013).[8] Below, we will just describe, in a rather telegraphic way, some of the important consequences of the *Hypothesis NEQ*.

As we have seen in the example of the human concept *Fruit or vegetables*, non-classical interference phenomena result from the fact that conceptual entities can combine to give rise to new emerging concepts, whose meaning cannot be reduced to the meaning of the individual concepts that form them. In the case of the double-slit experiment, we can explain the emergence of the interference fringes produced by the photons by considering that an impact on the final screen corresponds to the selection of a typical exemplar for the photonic conceptual entity in the state *The photon passes through slit A or through slit B*. In fact, the largest number of impacts (the brightest fringe) is located right in the middle between the two slits, that is, in the position that best expresses a condition in which it is impossible to determine through which slit the photon entity would have passed, if it were a spatial corpuscle.

As for the phenomenon of interference, also quantum entanglement results from the fact that when two (or more) conceptual entities are combined, their combination is the expression of a *connection through meaning*, containing potential correlations (i.e., correlations of the second kind). To give an example (Aerts, 2010b), the two human concepts *Animal* and *Food* can be connected through meaning in the conceptual combination *The animal eats the food*. This combination is the equivalent of an entangled state. Indeed, when a subject is asked to identify a typical exemplar of the concept *The animal eats the food*, choosing *in a coincident way* a pair of exemplars of *Animal* and *Food*, for example among the list of the animals *Cat*, *Cow*, *Horse* and *Squirrel*, and among the list of foods *Grass*, *Meat*, *Fish* and *Nuts*, it is evident that some pairs of exemplars will be selected

[8] See also the review article on the conceptuality interpretation published in this volume, by Diederik Aerts, Massimiliano Sassoli de Bianchi, Sandro Sozzo and Tomas Veloz.

more frequently than others, and one can show that these correlated pairs can be used to violate *Bell's inequality*.

According to the conceptuality interpretation, the violation of Bell's inequalities in experiments with microscopic entities in entangled states can be explained in the same way: being the nature of the microscopic entities conceptual, they can *connect through meaning*, a type of connection that in quantum physics is designated by the term "*coherence*." For example, in the well-known situation of a pair of spins in a singlet state, the entangled state can be considered to correspond to the conceptual combination *The value of the sum of the two spins is zero*, whose actualizable exemplars correspond to the different possible pairs of spin values having a zero sum.

Heisenberg's uncertainty principle can also be explained very effectively by the conceptuality interpretation. Indeed, a concept can be in states possessing *different degrees of abstraction* (or different degrees of concreteness). For example, in the ambit of human concepts, we can observe that *Food* is undoubtedly more abstract than *Fruit* (namely, the concept *This food is a fruit*), which in turn is more abstract than *Apple* (namely, the concept *This food is a fruit called apple*), which is more abstract than *The apple I have in my hand now* (namely, the concept *This food that I have in my hand now is a fruit called apple*). Abd this latter state of the human concept *Food* brings it into correspondence with the world of objects of our three-dimensional space.

We can therefore say that the most concrete (less abstract) state of a human concept is the one corresponding to the notion of an *object*, and that therefore objects are an extreme case of concepts, in a state of maximum concreteness. The uncertainty principle of Heisenberg would then be nothing but the expression of the fact that *a concept cannot be simultaneously maximally abstract and maximally concrete*.

In the case of a quantum entity, such as an electron, a state maximally concrete corresponds to an electron perfectly localized in the three dimensional space, at a given instant, while a state maximally abstract corresponds to a fully delocalized electron, that is, an electron in a state corresponding to a condition of maximal localization in momentum space. The non-spatiality of microscopic entities would then be an expression of the fact that most of their states are abstract states, whereas our three-dimensional space would only be a representation of the maximally concrete states of these conceptual entities.

With regard to the superposition principle, as already noted, concepts can combine together and give rise to new emergent concepts. This explains why quantum entities, as conceptual entities, are able to obey to the superposition principle, which should then be generally understood as a *combination principle*. The reason why the objects of our three-dimensional space do not obey, apparently, to the superposition principle, is that not all conceptual combinations of objects are still in a correspondence with objects, while all possible combinations of concepts always correspond to concepts.

More precisely, if we consider two objects, "A" and "B," then of course the combination "A or B" will not be anymore an object, while the combination "A and B" may still be considered to be an object (the object formed by the ensemble of the two objects). For concepts, however, the symmetry between the connectors "and" and "or" remains intact, in the sense that if "A" and "B" are two concepts, this will also be the case for the combinations "A or B" and "A and B," and for any other possible combination.

With regard to *quantum measurements*, they describe processes during which a conceptual entity, usually prepared in an abstract (superposition) state, acquires a more concrete state, through the indeterministic interaction with a structure sensitive to its meaning: the measuring apparatus. The quantum measurement processes of actualization of potential properties are therefore processes of instantiation of abstract concepts by means of an interrogative context, where the measured entities interact with the measuring apparatuses according to dynamics where the dominant element is the *exchange of (quantum) meaning*.

There would be much more to say about the conceptual interpretation, which we have presented only schematically here; for example, in relation to the possibility of explaining the key notion of *indistinguishability* (which appears in a very natural way in the conceptual entities, such as in the human concept *Ten cats*, which corresponds to the combination of ten perfectly identical entities), the *Pauli exclusion principle*, the emergence of "many-body effects" typical of quantum field theory, the distinction between the macro and the micro, the problem of *quark confinement* and of the existence of different *generations* of elementary particles, of *dark matter*, etc. But for this we refer the interested reader to the aforementioned articles.

Before considering the possible interest of the conceptuality interpretation in the clarification of the nature of the consciential extraphysical dimensions, it is worth observing that though it suggests that quantum entities are *concepts* and not *objects*, the conceptual entities associated with the microscopic "particles" must not be confused with the *human concepts*. The quantum entities would be conceptual only in the sense that the notion that gives rise to the "way of being" (the "beingness") of a quantum entity and of a human concept are the same, as for example the notion of "wave" can describe both the mode of being of an electromagnetic wave and of a sound wave. But other than that, they remain very different entities.

For example, when we talk about violating Bell's inequalities in the ambit of experiments with human conceptual entities (Aerts et al., 2000), the measuring apparatuses consist of single human subjects measuring specific combinations of conceptual (entangled) entities, by relating them to specific pairs of possible exemplars (see the example above). Therefore, we are not dealing in this case with measuring apparatuses formed by spatially separated parts, but with instruments formed by the minds of single human subjects, whose bodies remain well localized in space, in a condition of "macroscopic wholeness."

In other words, the non-spatiality of microscopic conceptual entities and the non-spatiality of human conceptual entities are certainly not of the same kind. The first is in relation to our three-dimensional physical space, the second in relation to a mental space of conceptual entities that are simply more concrete than those that are measured (in the sense of being formed by the exemplars of the possible outcomes of a decision-making process). Therefore, as with the quantum phenomena of which we have already discussed, in this case it is also important to avoid promoting undue confusions. For example, we can read in Tressoldi et al. (2010):

If quantum-like models are valid ways of understanding certain forms of perception and cognition, and nonlocal entanglement-like connections are inherently contained within such models, then it seems reasonable to expect some aspects of those isolated systems we call "individuals" to be more connected than they appear to be. Gaining information without use of the conventional senses, or "extrasensory" perception (ESP), might be one way that those connections might manifest.

Contrary to what Tressoldi et al. write, we think it is not at all reasonable, solely on the basis of the results obtained in quantum cognition experiments, to infer the existence of a non-spatial connection between the different individual minds. There is no basis for such an assertion since, as we just explained, the non-spatiality of quantum cognition has nothing to do with the non-spatiality implied by extrasensory perception phenomena.

In addition, it should be noted that even though our mental processes are governed by quantum mathematics, it does not mean in any way that our brain would be a quantum computer, as suggested for example in the Orch-OR theory mentioned in the beginning of this article. Even "classical" systems, when governed by hidden-measurement processes, are perfectly able to promote quantum or quantum-like dynamics. To quote Busemeyer and Bruza (2012), the research in the field of quantum cognition "[...] is not concerned with modeling the brain using quantum mechanics, nor is it directly concerned with the idea of the brain as a quantum computer."

17 Thosenes as conceptual entities

Having clarified the difference between the three-dimensional space of our ordinary experiences and the conceptual "spaces" associated with the different levels of abstraction of humans concepts, and the importance of not confusing them, we can now better appreciate what the conceptuality interpretation of quantum mechanics has to offer us, as a possible key to understand the nature of the consciential extraphysical realities.

One of the remarkable aspects of the conceptuality interpretation (in addition of course to that of possibly explaining the nature of the microscopic entities, which appear to us so strange just because we would erroneously think that concepts should behave as objects) is to reveal that the *interactions of a conceptual kind* are more abundant than what we could have imagined. In fact, the only conceptual entities that are usually identified as such are the human concepts. To these we can possibly today add (if we accept the hypothesis NQE) the conceptual entities belonging to the physical microscopic layer.

We can then ask whether the additional non-spatial layer associated with the CE reality, of which we can reasonably hypothesize the existence, would also be characterizable (or partially characterizable) as formed by entities whose nature would be typically conceptual. In other words, we can ask whether in addition to human concepts (that we intraphysical humans use to exchange meaning through various forms of communication) and microscopic quantum entities (that macroscopic bodies, such as the measuring apparatuses, "use" to exchange non-human quantum meaning, in the form of coherence), also the "subtle" extraphysical entities would be primarily conceptual. In this regard, it is interesting to consider the notion of *thosene*, as usually understood in *conscientiology* (Vieira, 2002; Minero, 2012).

A thosene is a element of reality that is considered to be the expression of a triad of inseparable elements: *e*nergy (also in the sense of matter-energy), *sen*timent (also in the sense of emotion) and *tho*ught (hence the neologism "tho-sen-e"). In other words, with the notion of thosene one wants to emphasize the possibility that in every existential dimensions of our reality, physical and extraphysical, a cognitive (and therefore also conceptual) element would be present, capable of conveying meaning, through the communication of energetic, emotional and mental apsects.

For example, when a psychic individual perceives the *energetic aura* of a person, the interaction is not only of the objectual kind. The "energetic" aspect of the aura corresponds, in a sense, to its most concrete manifestation, as the aura also conveys more "subtle" elements, more abstract we could say, containing potential information of a mental and emotional nature, which the psychic would be able to interpret.

To give another example, when we manifest in the consciential extraphysical dimensions, using the "subtle" vehicle called *psychosoma*, the "thosenic" aspect of our interaction with the different entities we encounter, be them living or non-living, predominates: everything becomes a vehicle of information and meaning and the way we react to the different extraphysical entities is mostly dictated by dynamics of exchange of meaning.

Also, in these extraphysical ambits, entities can come into "contact" without there being the need to be strictly present in a same "space of manifestation," by simply creating connections based on emotional or mental affinities. For example, a projector, to go from one extraphysical place to another, s/he will not necessarily have to follow a specific trajectory, as s/he can also create a connection with the place s/he wants to visit by evoking some meaningful elements of the same, in emotional and/or mental terms. This will generally be sufficient to produce an interaction, and the corresponding "teleportation," which therefore has nothing to do with the local modalities of interaction between ordinary (intraphysical) objects.

Of course, for the time being all this remains quite vague and speculative. What we want to underline is that the conceptuality interpretation of quantum mechanics is able to offer new and fascinating keys to understand not only the strangeness of the microscopic entities, but also, possibly, the strangeness of the more "subtle" dimensions of our existence, as well as the relations that exist between the physical and extraphysical layers, be them quantum or consciential. This intellectual exercise, however, must be conducted with a lot of discernment, so as to avoid producing overly superficial analogies, oversimplifications, or easy anthropomorphisms. To quote Aerts (2009b):

"*If we put forward the hypothesis that 'quantum entities are the conceptual entities exchanging (quantum) meaning (identified as quantum coherence) between measuring apparatuses, and more generally between entities made of ordinary matter,' it might seem as if we want to develop a drastic anthropomorphic view about what goes on in the micro-world. It could give the impression that in the view we develop 'what happens in our macro-world, namely people using concepts and their combinations to communicate' already took place in the micro-realm too, namely 'measuring apparatuses, and more generally entities made of ordinary matter, communicate with each other and the words and sentences of their language of communication are the quantum entities and their combinations.' This is certainly a fascinating and eventually also possible way to develop a metaphysics compatible with the explanatory framework that we put forward. However, such a metaphysics it is not a necessary consequence of our basic hypothesis, and only further detailed research can start to see which aspects of such a drastic metaphysical view formulated above are eventually true and which are not at all. We also do not have to exclude eventual fascinating metaphysical speculations related to this new interpretation and explanatory framework from the start. An open, but critical and scientific attitude is what is most at place with respect to this aspect of our approach, and this is what we will attempt in the future.*"

This warning also applies, *mutatis mutandis*, in relation to the hypothesis that the extraphysical entities studied by conscientiology, and described as *thosenes* (and more generally as aggregates of thosenes, called *morphothosenes* and *holothosenes*), would also be mostly of a conceptual nature. The fact that we can identify emotional and mental aspects in our ways of interacting with the more "subtle" entities which are present in the CE "spaces," and also in our ordinary physical space, when we use our psychic and para psychic abilities, could lead us to develop a purely human-centric vision of reality, where human consciousnesses would play a fundamental role.

However, as it is important to distinguish human concepts and quantum conceptual entities in the conceptuality interpretation of quantum mechanics, in the same way it is necessary to distinguish, in a possible extension of the conceptual hypothesis, human (ordinary) concepts and extraphysical (thosenic) conceptual entities. Also because, when we enter the field of exploration of non-ordinary states of consciousness, and of the more "subtle" realities associated with them, the distinction between inner (intra-psychic) and outer (extra-psychic) realities becomes much more nuanced, and this should lead us to move with greater caution.

Before concluding this article, we also want to evocate an aspect of the conceptuality interpretation that may be of interest in the exploration of the extraphysical existential dimensions. We mentioned already in the previous section that the conceptuality interpretation of quantum mechanics allows addressing a number of fundamental problems of physics in an entirely new way. Among them, we mentioned that of the different *generations of elementary particles*.

As described in the so-called *standard model* of particle physics, there are three different generations (or families) of elementary entities. Entities belonging to different generations interact in the same way, but differ in their quantum numbers and, especially, in their *masses*, that is, in their *internal rest energies*. For example, there are three kinds of electrons: the one belonging to the first generation is the electron that we all know, whose mass is $0.511\ \mathrm{MeV/c^2}$; then there is the electron belonging to the second generation, called the *muon*, whose mass is more than 200 times larger: $106\ \mathrm{MeV/c^2}$; finally, the electron belonging to the third generation, called the *tau* (or *tauon*), has a mass of $1777\ \mathrm{MeV/c^2}$, which is almost twice the mass of a proton.

The conceptuality interpretation of quantum mechanics provides a possible first element of explanation of the mysterious origin of these different generations (families) of microscopic entities. Citing

Aerts (2009b):

"*Could the generations of the elementary particles, electron, muon, tauon, and their corresponding neutrinos and the different generations of quarks correspond to different energetic realizations of the conceptual structure of the quantum particles? It is true that human concepts have different mass-energetic realizations as well: a word can appear in sound-energetic form, but also in electromagnetic form when transported electronically or in writing, or in its primitive form used by our ancestors, carved into stone. All forms have different mass-energies, but, since they represent the same concepts, they have the same properties.*"

In principle, this possible (and for the time being quite speculative) explanation of the origin of the different families of elementary entities can be extended and used to also explain the nature of the "subtler" dimensions of our existence, and of the "subtler" vehicles of manifestation that we individual consciousnesses use to manifest into them, as for example the previously mentioned psychosoma and mentalsoma.

One possibility is that these realities would correspond to different energetic realizations of a more abstract conceptual entity. For example, the various interconnected vehicles of the consciousness (the so-called *holosoma*, hypothetically formed by the combination of *soma*, *psychosoma* and *mentalsoma*), could be understood as the different energetic realizations of a conceptual entity that, in human terms, we would call the *The individual evolving consciousness*. But we must not confuse such a conceptual entity with the human concept that we use to denote it.

Another possibility is that the holosoma would correspond instead to a multi-vehicular structure formed by "bodies" corresponding to conceptual entities having different degrees of abstraction, the mentalsoma being more abstract than the psychosoma, which in turn would be more abstract than the soma.

18 Conclusion

Let us briefly summarize the main points that we have touched on in this article. Our main thesis was that quantum physics and consciousness are not usually taken seriously enough. In the case of quantum physics, to take it seriously means in particular to acknowledge that a measurement processes is a real, objective process, describing a physical and not a psychophysical process.

In that respect, we have shown that, contrary to the widespread belief that there would be no convincing *physical* solutions to the measurement problem, a theory with sufficient explanatory power does actually exist, which is able to account for the non-linear dynamics of the state reduction, called the hidden-measurement interpretation of quantum mechanics (Aerts & Sassoli de Bianchi, 2014); and we have also shown that once quantum measurements are taken to be objective processes, we are compelled to expand our world vision and acknowledge that our physical reality is much larger than what is contained in our limited three-dimensional theater, which is just the tip of an immense multidimensional (possibly infinite-dimensional) iceberg.

Another point we have tried to emphasize is that when the study of consciousness is taken with due seriousness, that is, when our first person experiences are considered without minimizing the richness of their content, we are also compelled to upgrade our vision of reality and acknowledge that it is very unlikely that our stream of consciousness would just be the by-product of our brain's activity, and very likely that it *also* results from the activity of more "subtle" vehicles of manifestation.

Another aspect we have highlighted in the article is the importance of not mixing up, a priori, the different extraphysical layers, as for the time being there are no reasons to believe there would be a direct correspondence between the quantum and consciential elements of our reality. Both elements are certainly non-spatial in nature, in the sense of corresponding to extraphysical realities taking place outside of our three-dimensional Euclidean space, but as far as we know their structure is not equivalent.

Finally, we have also explained what it means to take seriously the recent progresses in quantum cognition. Our warning is about not confusing the quantum modeling of human cognition with the hypothesis of a non-local (non-spatial) quantum mind. Indeed, it is only when we avoid such confusion that we can fully appreciate what quantum cognition has to offer us, as an explanation regarding the nature of the non-spatial entities populating the extraphysical layers of our reality.

We think that this new explanation is contained in the so-called conceptuality interpretation of quantum mechanics (Aerts, 2009b, 2010a,b, 2013), which can possibly be extended to also include the description of the more "subtle" consciential realities. However, and again, this must be done with great discernment, that is, without unduly mixing the different conceptual layers.

We conclude with what we think is an important remark. It is generally believed by "post-materialistic scientists" that the materialistic paradigm should be abandoned and replaced by a more evolved one, able to account for the "psi phenomena." However, we should consider that what is really at the foundations of materialism is not, as many believe, the denial of the extraphysical consciential realities, but the requirement to found our conception of existence on a *substantial* basis (something exists, and therefore is real, if it exists in a substantial sense). This means that the unprejudiced materialist will not be a person willing to deny anything, but simply *to affirm existence on a substantial basis*.

In that respect, we think that also the so-called *consciential paradigm*,[9] if correctly understood, is a materialistic paradigm. The only difference with respect to conventional materialism is that it acknowledges a wider spectrum of substances, some of which are of a non-ordinary kind, like those forming our more "subtle" vehicles of manifestation. In other terms, the consciential paradigm is just about replacing materialism by *multimaterialism*. However, this will not be sufficient to solve the *hard problem of consciousness*, and the more general *mind-body problem*, which will only be reframed in a wider context, in what we may call the *mind-holosoma problem*.

Modern physics has also brought physicists (at least those who are willing to abandon the prejudice that our three-dimensional space, or four-dimensional space-time, would contain the whole of reality) to contemplate a much ampler non-spatial reality. This means that physicists and "conscientiologists" (individual studying consciousness from a multidimensional perspective) have to face the same challenge: that of explaining the nature and behavior of non-ordinary substances. It is therefore possible that, in the course of their

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[9] The consciential paradigm considers that individual consciousnesses (like human consciousnesses) are intelligent principles manifesting through energetic multivehicles (the holosoma), in multidimensional environments and multiexistential cycles (Vieira, 2002).

investigation, they will be brought to develop similar models of reality; not because these model would address the same elements of reality, but because similar "patterns of interaction" would be at play at the different levels of reality; and it is very possible that the "conceptuality model" of quantum mechanics and the "thosenic model" of conscientiology, proposed long before also by the ancient science of Yoga (Sassoli de Bianchi, 2010), are just two different ways of expressing a same pattern of interaction.

Appendix: telepathic creation of correlations

As far as we know, telepathic experiments typically use protocols where a subject A tries to send some information to a subject B, who then tries to identify it. This is essentially a protocol of transfer of information. As we explained in the article, quantum entanglement cannot be used to directly transfer information, and this means that a telepathic communication requires more than just quantum correlations, at least as usually understood [For a more general approach, see Aerts et al. (2019)].

However, if two subjects were able to create some form of mental connection, and use it to produce correlations in a statistically significant way, this would be already sufficient to highlight a genuine psi phenomenon. Such phenomenon would not be that of a telepathic communication, as no information would be transferred, but of a *mental entanglement and mental creation of correlations.*

Our conjecture is that since a transfer of information is more demanding than a creation of correlations, an experiment that would only seek to highlight the latter could possibly obtain more favorable statistics of outcomes than what is usually obtained in the "transfer of information" protocols (like in so-called *ganzfeld experiments*). Considering the example of the string, a possibility would be for instance that of creating a *mental string*, to be mentally stretched between the two subjects, who would then be asked to break it, at some moment, in a coincident way. Following this mental breaking-measurement, they would then be asked to determine if the string fragment in their mental hand is longer or shorter than that of their colleague (that is, longer or shorter than half the length of the original mental string).

Four couples of answers are possible: (short, long), (long, short), (short, short) and (long, long). Only the first two are expression of a correlation: can they be obtained more frequently than the last two, in a statistically significant way? And what will be, typically, the *p-value* of mental experiments of this kind? We invite the parapsychologists to test the efficaciousness of this "creation of correlations" protocol.

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Invitation to read

Universal measurements

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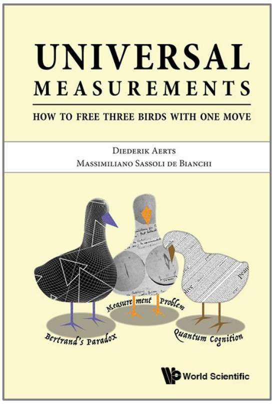

This is a book presenting to a wide audience of readers, ranging from fans of science to professional researchers, some of the authors' recent discoveries in three distinct, but intimately related domains: probability theory (Bertrand's paradox), observation in physics (the measurement problem) and the modeling of experiments in psychology (quantum cognition). In all three of these domains of investigation, and the associated problems, the authors explain how to advantageously use the key notion of universal measurement, which constitutes the fil rouge of the whole text.

Excerpt: In several languages […] an important distinction is made between two different forms of lack of knowledge. In Italian, for example, we have the term "aleatorio" (or the equivalent term "azzardo", i.e., "hazard" in English), indicating a danger, a risk, that is, something that can happen to us and that in no way we can control. We find the same meaning for example in the Dutch term "toevallig," from "fallen," which means "to fall," and "toe," which means "towards you." So: "that which falls towards us," which can "happen to us," such as losing money in a bet with nuts, that is, in a game of chance ("gioco d'azzardo," in Italian).

In Italian, there is however also the term “arbitrario” (“willekeurig” in Dutch, “arbitrary” in English), which designates “what depends on the will or opinion of a single individual,” such as when we decide to perform a particular experiment rather than another. In other words, our ancestors, at a time when language was developing, were already aware of the difference that existed between the randomness produced by the objects of their experience, expressed by the word “hazard,” and the randomness produced by themselves, that is, by their actions, as subjects able to make choices, expressed by the word “arbitrary.” When we carry out an experiment, these two forms of randomness are always present, provided nothing intervenes to control them. The first form corresponds to the level of unpredictability associated with the experiment itself, once the protocol to be followed has been defined, while the second corresponds to the experimenter’s lack of knowledge about the experiment s/he will actually choose (or has chosen) to perform. Usually only the first type of randomness is taken into account in physics, both in conceptual and in formal terms. This is so because it is believed that the selection of the experiment to be performed is a process always under the full conscious control of the experimenter, and so, in that sense, it would not be random. But this is not always the case, as we have tried to highlight in the present essay.”

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