Chapter 5

Quantum Theories without Observer as Theories about the Wave Function

In contrast to what we have seen in the previous chapter, cBM (the view that Bohmian mechanics is about a particle and the wave function in configuration space), GRW∅ (the view that GRW is about the wave function), MW∅ (the view that many worlds is a theory about the wave function) share the following feature: the wave function has not some fancy or weird status, as suggested by what we have seen in the previous chapter. Rather, it is part of the ontology at most fundamental level. That is, f it is the case, it exists as a physical, material field. In cBM, the wave function is part of what constitutes ourselves and the rest of physical objects, together with a particle in configuration space; in GRW∅, and in MW∅, the metaphysics is simpler, since there is only the wave function.

In all these theories, physical space is configuration space and physical objects are made of wave functions. In this framework, three-dimensional space and all the macroscopic world are emergent from the description provided by the wave function. In the case of GRW, also the mass density and the flashes in GRW are "emergent": GRWf and GRWm are not two different theories. Rather, as stressed by Lewis in his *GRW: A Case Study in Quantum Ontology* (P. Lewis 2006), they provide different ways of describing what happens using different languages. Let us analyze how this emergence is supposed to take place.

5.1 Three-Dimensional Space as Emergent

In the framework of the approach according to which the wave function is a matter field, physical space is configuration space, we need some map to recover the appearance of three dimensional space. As we pointed out in Chapter 3, an entity in configuration space does not specify an arrangement of objects in ordinary three-dimensional space. An entity in configuration space is given by specifying the values of $3N$ parameters, but nothing intrinsic to the space specifies which parameters correspond to which particles in three-dimensional space. In order to specify a configuration of particles in three-dimensional space, a particular correspondence between parameters and particles must be added to the wave function representation. As we have discussed previously, Albert proposes that the Hamiltonian is the one that is understood as providing the connection between configuration space and three-dimensional space as a practical matter. A similar way of thinking is the one of Rimini about GRW, one of the proponents of the theory, who provides a similar explanation (Rimini and Nicrosini 2003). It is because the Hamiltonian has the form that it has that the world appears at us as if it were three-dimensional, even if it is not.

Let us now consider the following question: What are the reasons for which the Hamiltonian is the way we write it? It seems rather straightforward to me that the reason we use a certain Hamiltonian H and not another, call it $\tilde{H}$, is that we already assume that physical space is three-dimensional space and H, the actual Hamiltonian of the theory, works better in explaining the behavior of matter in three-dimensional space than $\tilde{H}$, the one that we did not choose. Therefore, it seems that the explanation structure in Albert's view is upside down: is it the structure of the Hamiltonian that explain the appearance of the three-dimensional world or the existence of such a world that explains the Hamiltonian?

In addition, arguments against the possibility for the Hamiltonian to provide the correct rule of correspondence are given by Bradley Monton (Monton 2002). On the one hand, Albert stresses that the Hamiltonian determines that the world appears three-dimensional to its inhabitants, even though such appearances are nonveridical. But Monton responds that

> [...] the naturalness of the correspondence does not get us anywhere. It isnt the case that we can select the natural correspondence and forget about the rest; since there is no three-dimensional space, each correspondence is equally real, or (if you prefer) equally unreal. To say that one correspondence is natural is to make an

> epistemic claim about how we judge correspondences. There is no ontological import to that claim (Monton 2002).

As already noted, this is connected with the problem of the preferred basis: since the wave function can be written in many basis, what determines the preferred basis? What makes that particular basis the "right" choice? Some have replied (see (Barrett 2003) for a review) with some sort of evolutionary argument: evolution has selected us in such a way that it is advantageous for us to have them in that basis. But it is not at all obvious that there is some evolutionary advantage to this.

Others have proposed that decoherence should play a role in this (see (Wallace 2003)) but, as already noticed, this is very much a work in progress.

5.2 Macroscopic World as Emergent

In addition to a map that should be used to explain why we believe we are in a world that is three-dimensional, we also need some account of the properties of the objects we see all around us. This is connected to the so called problem of the tails discussed in (Albert and Loewer 1996) and summarized previously. In the case of GRW∅, as we saw, Albert and Loewer suggest that the so called eigenvalue-eigenstate link cannot account for the properties that we observe in the framework of GRW theory, since the wave function after the random collapse would not be an eigenstate of any operator. Their proposal therefore is that we should use a different rule of correspondence, which has been called the fuzzy link, according to which if the square of the wave function as a function of $x \in \mathbb{R}^3$ integrated in a certain region S is "sufficiently" close to 1, then we are entitled to say that there is a "particle" localized in region S, where "sufficiently" is characterized by a certain parameter p, such that $1 - p \sim 1$. In this way, they say, it is possible to recover what we usually mean when we talk about localizable objects on the macroscopic level and the appearances of those objects to be localized while they are not.

Peter Lewis discusses what he calls the problem of interpretation of spontaneous collapse theories (P. Lewis 2006). He starts from the problem that, if the wave function constitutes physical objects and if it randomly and spontaneously collapses, we need to account of why we perceive physical objects having certain properties. This is the problem of the tails:

> In its most general form, the worry is that the GRW theory cannot, after all, ensure that objects have the determinate properties that we observe them to have, since determinate properties require that the wavefunction is an eigenstate of the relevant operator, and the GRW theory does not in general yield such eigenstates. But this is just the measurement problem all over again; the tails problem calls into question the GRW theory's claim to solve the measurement problem in the first place.

In the case of GRW, three different links, he says, have been proposed to solve this problem: the fuzzy link, the mass density link, and the flashy link. They provide a rule of correspondence between the descriptions provided in terms of the language of the wave function and our everyday description. In other words, they are translation rules. Lewis notices that that one can take these links to be ontologies rather than rules of translation. The mass density and the flash link are alternative links to the fuzzy link.

The crucial thing to notice is that all these links are not additional ontologies in any way: they do not represent anything in the physical world. Rather, they are just practical rules that should be added for epistemic purposes. Therefore, in this framework, since the links provide just different translations, GRWm, GRWf and fuzzy GRW are not really different theories. In addition, it does not matter that these rules are not precise: it is just a matter of understanding how appearances of the world arise from a fundamental physical theory, how we can match the language that we use every day to describe the physical objects with the description provided by the theory.

This approach is completely different to the approach based on the notion of primitive ontology: in GRWf and GRWm, an ontological rather than practical rule has been introduced. It is not just a rule to recover the three-dimensional space out of the configuration space but it is much more that that: what is defined by this new rule is what the theory is about, it is what tables and chairs are made of. Specifying that "rule" amounts to specifying the primitive ontology of the theory.

The fuzzy link has never been considered as an ontology, so Lewis focuses only on the mass density link and on the flashy link. He provides two arguments, and none of them is very convincing in my opinion, that we should regard these links as practical and not ontological. The first argument he provides against these translation rules being ontologies is that the mass density link and flashy link supervene on the wave function. Because of this supevenience, there is no real need to add them over and above the wave function. I think that this argument is unconvincing: first of all, the fact that we have (unspecified) supervenience of the mass density and the flashes on the wave function does not have any bearing on them being additional ontology, as we have already discussed in the previous chapter. We will come back to it also later in this chapter, in the section about reductionism. One might say that we would not be having the problem of the tails if we would drop the idea that the wave function constitutes physical objects. Lewis' second argument is that there seem to be no reason to do so: after all, it is part of the dynamical laws. Also, I hope that the previous chapter would have been sufficient to show how this is false.

Lewis, and Albert and Loewer have discussed the problem of the tails in the case of GRW∅, but, as we saw, also cBM and MW∅ have the problem of the tails and therefore need a "link". A link should be proposed also for MW∅, otherwise it is not clear what properties of macroscopic objects correspond to. From what we have seen before, we have different possible links for MW: the fuzzy link corresponds to MW∅, the mass density link corresponds to Sm, and theflash link to Sf. Again, if we take them to be rules of translations, they are not different theories. Also in BMc we should provide links. The fuzzy link seems to be appropriate. What about the possible descriptions in terms of the other possible links, the mass density and the flashes? In any case, they are just different descriptions of the same theory, BMc.

David Albert [1] argues that it is possible for these links to emerge from the description in terms of the wave function, but this is unclear how it is supposed to be accomplished.

5.3 Many Worlds and the Stability of Macroscopic Properties

Supporters of MW∅ have emphasized that, in order for the theory to be sensible, it needs to account for the fact that the properties that we attribute to the macroscopic

[1] Private communication

objects stays the same in time. That is, we need to guarantee the stability of the classical world. That would amount to guarantee, in MW∅, that, since objects are patterns defined by the wave function, the different branches of the wave function do not interfere anymore after a while. This is supposed to be accomplished through the effect of decoherence: after a short time, the interference terms go to zero so that we can consider the two branches as constituting different worlds.

But if objects are defined as above, then all the bare theories described here (GRW∅, MW∅, and arguably BMc) are many worlds theories. As emphasized by Alberto Cordero in his *Are GRW Tails as Bad as They Say?* (Cordero 1999), in theories like GRW∅, when the wave function collapses due to the stochastic evolution, the small piece corresponding to the collapsed piece of the superposition still remains, and a small piece is still a piece. So why is that the small term in the wave function does not represent physical objects, if it possesses all the same features as the big one? In all these theories we need decoherence to separate the branches and guarantee the stability of the classical world.

In cBM, since we deny the particles trajectory a primitive status, one can arrive to the conclusion that the trajectories have no influence on the outcomes of experiments and are thus superfluous. In addition, since the wave function does not collapse, one would then have to regard, as one is supposed to in the many worlds view, all outcomes of a quantum measurement as being realized. So also in cBM we need decoherence. An argument that the trajectories are not really necessary has been made in the already mentioned paper by Brown and Wallace (Brown and Wallace 2005). They take up an argument by David Deutch in which he claimed that, since the way in which Bohmian mechanics solves the measurement problem does not involve the corpuscles in any way and therefore, the particles are not really needed and they are redundant. As a consequence, we can think of

> pilot-wave theories are parallel-universes theories in a state of chronic denial (Deutch 1996).

Wallace and Brown continue noticing that Everett, since it has a simpler structure, is a better solution of the measurement problem when compared with Bohmian mechanics.

In detail, here is the argument:

1. In the case of one particle, the wave function determines the actual measurement result (what Brown and Wallace call "Bohm's result assumption"),

2. If [1] is true for one particle, then it is true also for N particles.

3. Therefore, the particle does not serve any purpose.

Obviously, if one instead insists that in Bohmian mechanics the wave function is not a physical object, the argument falls apart. Peter Lewis in (P. Lewis 2007) takes on this challenge and proposes to hold that the wave function is physical but that "empty" branches are different from "full" ones. But if we identify macroscopic objects with patterns of behavior, as Wallace suggests (Wallace 2003) following Daniel Dennett (Dennett 1991), then empty and full waves seem to instantiate the same pattern. If that is true, then what is the difference introduced by the particle? A possibility is to stipulate that empty waves and waves with particles do not instantiate the same pattern and therefore represent different macroscopic objects. They would represent the same object if we identify patterns with what they do, but we can stipulate differently what patterns are identified by.

5.4 Configuration Space: Wild, Wild Metaphysics

It is crucial to notice that the picture of the world that this view gives us is very radical: for example, if GRW∅ is true as complete description of the world, then the world is composed by the wave function, which lives in this very highly dimensional space. The same is the case for MW∅. And if cBM is true, then there are a particle and the wave function, both in configuration space. And all the rest is there: all the complexity, all the variety, all the identity, all the multiplicity of things is in this value: $\psi(q)$, where $q \in \mathbb{R}^{3N}$ is the configuration of the universe. Tables and chairs, apples and planets, reptiles and cats, humans and Martians, ... : they are not made of particles, they are not made of fields in $\mathbb{R}^3$, rather they are all there, together, described by the wave function in $\mathbb{R}^{3N}$. You, me, our friends and families, serial killers, Mother Theresa, George Bush, ... : we are all there. As also Monton (Monton 2002) points out, this view is even more radical than the "brain in the vat" scenario: at least in that case brains are in space-time, while in this view there are basically no brains as we think of. There are no individuals at all! I believe I am in a three-dimensional space, but I am mistaken; I believe that there are objects separated from me, but I am mistaken; I believe that when I say "there is a table over there" I am saying something (at least in a reasonable sense) true about the world, but I am mistaken; I believe I have an identity as an individual, but I am mistaken; I believe that I am having individual experiences, but I am mistaken; I believe that I am using the word "I" coherently, but I am mistaken! That is, I am (and you are) mistaken about the whole entirety of my beliefs, including the one that Descartes was telling us that I cannot be mistaken about, namely that there is somebody who thinks! And this is one of the least believable thing of all, since it seems clear, starting from Descartes, that I can put into doubt almost anything but the fact that I have experiences!

Now, as a matter of methodology, as we did in the case of Wigner's solution to the measurement problem, I think that before accepting some radical view we should establish whether or not there are strong reasons to really reject more "natural", less revisionary perspectives. Or, if we can gain some further understanding adopting the more radical view. Albert's theory seems far too radical than is needed: it is possible that the world is like he claims it is but but there seems to be no reason to believe it is the case. In fact, it seems we can perfectly do without it: what is so wrong with the alternative view that the world *is* actually three-dimensional to justify the acceptance of such a revisionary view of the world? I do not see any justification. What further understanding is gained adopting this new view? I cannot see anything either. Rather, just the opposite: if we adopt this radical view we need to supplement what we have so far with further explanations.

More work needs to be done, and the amount would be enormous. In fact, as we saw in the previous section, Albert's approach with the use of the Hamiltonian is primarily concerned with how to explain the (false) appearances of the world around us as three-dimensional given that the world is actually $\mathbb{R}^{3N}$. But before explaining why my perceptions mislead me in thinking I live in $\mathbb{R}^3$, in this theory I should explain why my perceptions mislead me in thinking I am myself and I have perceptions at all. In fact, as we have pointed out above, there are no "individuals" of any kind in the theory, just the big, holistic, highly dimensional wave function. In contrast, according to the alternative based on a primitive ontology in space-time, the world *is* three-dimensional, we are three-dimensional objects, and our individual perceptions about them are not put into question. In fact the idea behind these theories is that starting from a microscopic ontology in $\mathbb{R}^3$ as the physical space, we would end up recovering all macroscopic physical properties (temperature of a gas, ductility of a metal, elasticity of material, transparency of glass, and so on). If we adopt this approach we do not have to worry about explaining misleading perceptions. We are still left with the gap between the physical and the mental, but whether one considers this gap in principle unclosable by physics or not, it has no implication in physics as we know it today, since physics does not directly talk about perceptions. This is the main reason for which it seems more sensible to choose right from the beginning a primitive ontology in three-dimensional space to explain the behavior of macroscopic in three-dimensional physical objects instead of having a primitive ontology in some abstract space and then be obliged to derive my own (mistaken) perceptions of the world. As a consequence, a necessary condition for an adequate primitive ontology is that it is three-dimensional space.

To put it differently, there are two problems: first, we want to explain the behavior of macroscopic objects in three-dimensional space in term of the motion of microscopic objects in three-dimensional space. Then the second problem is to try to explain why we have the perceptions that we have, given that the physics is what it is. I think physics should deal with the first problem, the second problem being the mind-body problem. If a fundamental physical theory is intended to be about a primitive ontology in three-dimensional space, the mind-body problem is left to a (future) theory of consciousness or a more complex physics. Once we have left perceptions out, we can dedicate physics to the description and the explanation of the motion of bodies in three-dimensional space. On the wave function approach, in contrast, we have a completely different view of what physics is supposed to be: physics is required to explain right away the origin of perceptions in order to start explaining everything else. Physics as we know it and the theory of consciousness are completely merged in this approach and therefore everything becomes more difficult at any level, since no one has a theory of consciousness. Notice that what it is claimed here is not that we should not aim at such a complete theory. But given that the physical world is or seems to be causally closed (given that we have been able to do physics until now), we can do physics without having to have a theory of consciousness. What is gained, then, not to do that and entertain the wave function view? To put it differently, I agree with Chalmers when he writes:

> [...] heat is naturally construed as the cause of heat sensations. Does this mean that we have to explain heat sensations before we can explain heat? Of course we have no good account of heat sensations (or of experience generally), so what happens is practice is that that part of the phenomenon is left unexplained. [...] To be sure, no explanation of heat will be complete until we have an account of how that causal connection works, but the incomplete account is good enough for most purposes. It is somewhat paradoxical that we end up explaining almost everything about a phenomenon except for the details of how it affects our phenomenology, but it is no problem in practice. It would not be an happy state of affairs if we had to put the rest of science on hold until we had a theory of consciousness (Chalmers 1996).

As also emphasized by Maudlin (Maudlin 2006), we do not need to mention the mind-body problem in classical mechanics because the evidence is stated in the language of local physical fact and not in the language of experience. All you need to do is to explain how experiences, say, *as of* a rock are experiences of a rock and then physics can take care of that. If we don't have a primitive ontology in space-time, the only connection can be made at the level of experiences. So you cannot avoid to discuss about how conscious experiences come about. Indeed, if we don't have a primitive ontology in three-dimensional space, physics would be very different than what it is right now.

One should also notice that, if one considers the gap between the mental and the physical as unclosable in physics (as, for example, a particle dualist would think), then the approach of the quantum theories about the wave function will *never* be successful: one needs to be a physicalist in order to believe in cBM, GRW∅ and MW∅. If one really wishes to insist that consciousness has a role in physics, a theory like Wigner's or the many minds theory seem more adequate. In contrast, a non-physicalist that wishes to keep consciousness out of physics would for sure prefer a quantum theory without observer based on a primitive ontology in three-dimensional space as described in the previous chapter.

5.4.1 Is Configuration Space really $3N$ Dimensional?

Incidentally, I would like to note that Peter Lewis (P. Lewis 2004) provides a reply to the objection that the wave function ontology is vastly revisionary and that has to recover three-dimensional space since the real space is $\mathbb{R}^{3N}$. His strategy, as I take it, is to deny that, for all practical purposes, physical space is configuration space. Rather, also the wave function can be suitably identified as living in $\mathbb{R}^3$, even if, in some respect, it can be thought as living in $\mathbb{R}^{3N}$. That is, there is a sense in which the wave function lives in three-dimensional space and another one according to which it lives in configuration space. I find this argument very unconvincing, but for completeness, here it is:

1. The Hamiltonian H has to be invariant under choice of coordinate system, so its sufficient to specify the origin and the three axes,
2. H has to be invariant under arbitrary origin shifting (so that we can pick up any location to be the origin): this would represent an N-particle system where all the particles have some position in $\mathbb{R}^3$,
3. In order for H to be invariant, the only possible transformations are the one that perform a transformation on the triplets in Alberts grouping,
4. Therefore the wave function lives in $\mathbb{R}^3$ if we define dimensionality in terms of possible coordinate transformation and not in terms of number of parameters.

As Monton in his *Quantum Mechanics and 3N-Dimensional Space* (Monton 2006) replies to Lewis, in the argument above [4] does not follow from [3] since the definition of dimensionality provided by Lewis does not capture our standard concept of

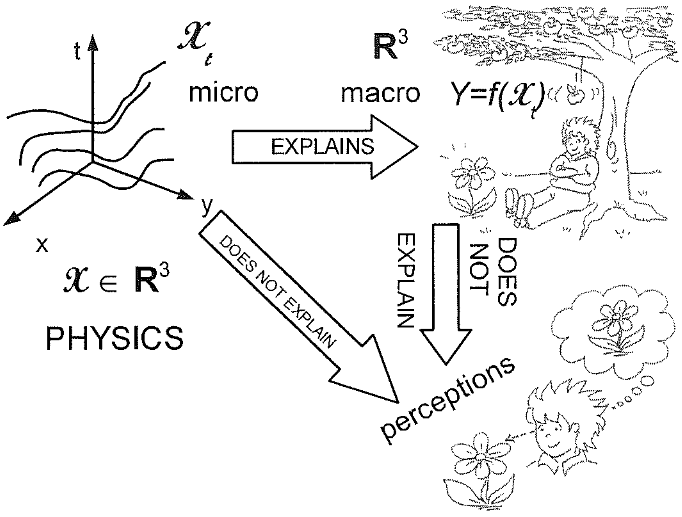

Figure 5.1: Explanation in quantum theories about a primitive ontology in three-dimensional space.

dimensionality. According to Monton, the correct notion of dimensionality is constructive: we first start from the the point, which is the 0-dimensional primitive object, and then we construct on it the higher dimensions. Dimensionality is a metaphysical matter while Lewis's argument makes it "scientific". My take is that Lewis's approach to dimensionality is just bait and switch: we all know what "dimension" means and what Lewis is doing here is just using the same term with a different meaning. Lewis's strategy solves a real, metaphysical issue with a terminological turn and this is cheating. It is like responding to the problem of evil argument that suffering is not real: who do we think we are convincing? The argument is far fetched and really hard to believe, but this is what needs to be done if we wish to insist that the wave function is a physical field.

5.4.2 Configuration Space and the Space of String Theory

Here is another parenthetical remark. One might think that, given what we concluded above, that is, that three-dimensional space is special, we should also reject string theory. The reasoning might be the following: in string theory physical space is supposed

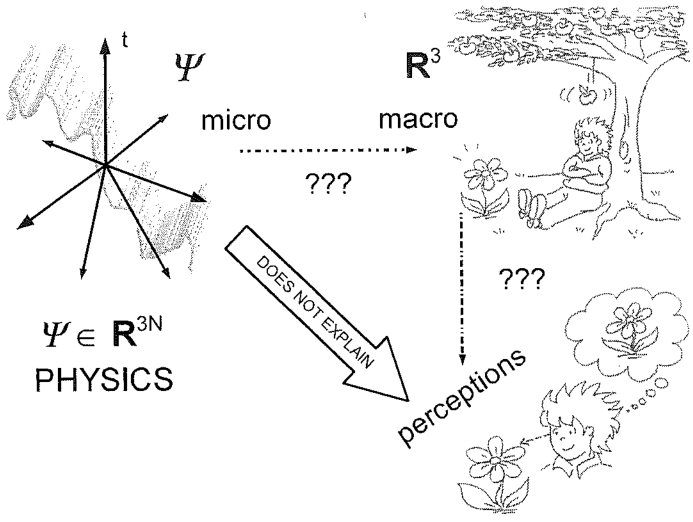

Figure 5.2: Explanation in quantum theories about the wave function.

to have 10 dimensions; in configuration space we have M dimensions, with M some non-prime natural number; 10 is a non-prime natural; therefore, the case of string theory should suffer from the same kind of objections we raised for configuration space.

I do not think this reasoning is correct. In fact in string theory the starting point is that the number of dimensions of physical space is greater than three. At the same time, though, it is assumed that all dimensions except three are compactified and scientists still looks for a mechanism that would explain why that is the case. Indeed, string theorists hope to find a unique way of compactify the extra dimensions, that is, a unique string theory. Then in this case, assuming extra dimensions and then compactifying them, string theory could explain features of our world (such as the vacuum state) that have been left unexplained by the previous theories.

This should make clear that the approach of string theory is completely different from the one of configuration space. In string theory the extra dimensions are added but they are promptly compactified, in order to keep the world *objectively* always like $\mathbb{R}^3$. There is no need to talk about perceptions in order to explain the world as three-dimensional.

In this respect, let me note that one could raise a very similar objection as the one that Cordero had to bare GRW∅ also to GRWm arguing that GRWm is a many worlds theory without the objection being so devastating: the small portion of the collapsed wave function defines a small mass density field that instantiates the same pattern (that is, that describes the same macroscopic object) as the mass density field defined by the big, peaked portion of the wave function. But this is just a counterintuitive consequence of GRWm, not a knock-down critique: as in string theory all of the dimensions except three are "compactified" such that we do not see them, in GRWm there are small copies of objects that always come together with the one we experience.

5.4.3 Configuration Space and Space-Time

I would also like to stress the following. Consider the theory of relativity: one could think that this theory brings about the lesson that space and time are not fundamentally distinct because they appear into the laws in the same manner. But what is the explanation of the fact that we perceive them differently? Einstein warned us that we will never be able to explain, in physics, our sensations, included the one concerning the passing of time. In any case, on the one hand relativity suggests that space and time are of the same kind, on the other it does not explain why we do not perceive them equally. A analogy can be drawn again with quantum mechanics: on one hand it suggests that physical space is $\mathbb{R}^{3N}$, on the other hand it does not explain why we perceive it as $\mathbb{R}^3$. If one accepts the position that in relativity physical space is $\mathbb{R}^4$ and not $\mathbb{R}^3$, then why not accept that in quantum mechanics physical space is $\mathbb{R}^{3N}$?

A possible position is the one of Tim Maudlin in his *Remarks on the Passing of Time* (Maudlin 2002), that rejects both positions: space is three-dimensional and it is fundamentally different from time. A position that might seems a little more difficult to justify is the one I would like to entertain, that is, we can accept that space is fundamentally not distinct from time while we do not accept that physical space is highly dimensional. Indeed, it seems sufficient to recall that in relativity it is always possible to separate space from time and to recognize the objects around us without invoking some theory to explain our perception of time (something that it is not possible to do in the case of physical space being $\mathbb{R}^{3N}$) to stress the difference between the two cases in favor of my position. In other words, given an observer, the metric (which should be included in the primitive ontology of the theory of relativity) gives us the natural separation of $\mathbb{R}^4$ into space and time: for a given observer, there is always a way to tell how things are for a given world line. Therefore, the situation in relativity is, in my opinion, far less extreme and therefore far more acceptable, that the one required by bare theories like GRW$\varnothing$, that is indeed not acceptable.

5.5 Different Kinds of Reductionism

One might asks the following question: What kind of explanation is the one provided by this bare approach? If the world consists only in a field in some high-dimensional space and in its evolution in time, do we consider such a theory a good scientific theory? Do we think it really explains the world around us? As we just saw, taking the wave function as primitive ontology seriously involves a very radical reductionist position: we have to explain our perception of three-dimensional space, the appearance of the existence of tables and chairs, apples and cats as individual and localized objects in that space, from the behavior of the wave function, that lives in a highly dimensional space.

In the previous sections we discussed emergence. When we say that a given macroscopic property Y emerges from the microscopic description provided by X we mean that Y can be recovered from or (suitably) reduced to X. The proponents of bare quantum theories without observer have claimed that the perception of three-dimensional space and the macroscopic world in general emerge from the description provided by the wave function.

While the reductionism of the macroscopic properties seems to be acceptable, the one of the perception of three-dimensional space does not. One might notice that, something similar, it seems, has been accomplished in the case of color: it is not necessary to postulate that red or redness exists, once we have described something red in terms of electromagnetic waves interacting with our retina (even if with that we did not explain why we perceive it as "red"). Calling an object "red" means that the wave length that

	QTWO$\varnothing$	QTWO$\mathscr{X}$
3d world	emergent (H, deco)	fundamental
Macro World	emergent (links)	function of $\mathscr{X}$
Stability of Macro	deco	deco

Table 5.1: Comparison between bare quantum theories without observer (QTWO$\varnothing$) and quantum theories with a three-dimensional primitive ontology (QTWO$\mathscr{X}$).

it reflects belongs to a given interval. The convention is purely pragmatic because that interval is arbitrary: excluding some wavelengths on the boundaries does not make much difference. Why cannot we play a similar game in the case of our perception of three-dimensional space? It might seem that there is no use of postulating that $\mathbb{R}^3$ is the physical space because, as Albert would claim, we can explain why it appears to me like that because of the shape of the Hamiltonian.

While it seems reasonable to postulate that the color can be reduced, the case of the perception of three-dimensional space seems a different kind of reductionism. A color, like "red", is just a macroscopic property, we could have used "round" or "solid". The claim that we can explain them away seems acceptable. In fact, notice that I said "color", not "perception of color". In contrast, the case of the reduction of the perception of color, is of the same degree of magnitude as the reductionism of the perception of three-dimensional space: we have the problem of the explanation of perceptions, the mind-body problem, that suggests that they are not reducible to microphysical facts.

5.5.1 Reductionism of the Macroscopic World

We have seen in Section 4.9 that in the framework of quantum theories with a primitive ontology in three-dimensional space the properties of macroscopic objects can be completely described in terms of the primitive ontology, since there is logical supervenience. Also in the framework of the quantum theories about the wave function in principle we could have a similar logical supervenience and therefore a similar reductionism of the appearances to the wave function, the links discussed above providing the supervenience function. But these links do not express logical supevenience. To understand why it is the case, let is analyze an example of failure of reductive explanation.

5.5.2 The Impossibility of the Reductionism of Perceptions

Let us analyze, as an example, the case of the relation between the mental and the physical. As Chalmers has emphasized in more than one occasion (Chalmers 1996), (Chalmers 2002), there are two problems, on the line of those discussed above: the "easy" problem and the "hard" problem. The easy one amounts to explaining certain cognitive functions, and it seems more like solving a problem rather than a mystery. The hard problem is the problem of experience: Why is the performance of these functions accompanied by experiences? How does the physical give rise to the mental? Philosophers have tried to provide a reductive explanation of consciousness: explaining consciousness in terms of natural principles. We have physicalist solutions, according to which consciousness is reducible to the physical, and we have non-physicalist solutions, according to which consciousness is not physical. Chalmers, among others, argues that we cannot have any reductive explanation of consciousness. Let us consider the "explanatory argument", one of the standard arguments against materialism, that is against the possibility of reductively explain consciousness in terms of physics:

1. Physics accounts only for functions and structure,
2. Functions and structure are not enough to explain consciousness,
3. Therefore the physics cannot explain consciousness and materialism is false.

As Chalmers emphasized (Chalmers 2002), this argument tries to establish an epistemic gap between the physical P and the phenomenal Q: It denies an epistemic entailment from physical truths to phenomenal truths. And once one has established the epistemic gap, one then infers that there is in addition an ontological gap between P and Q:

1. There is an epistemic gap between P and Q,
2. If there is an epistemic gap, there is an ontological gap,
3. Therefore materialism is false.

To say that there is an epistemic gap but not an ontological gap amounts to saying that reductionism is possible, at least *in principle* even if not in practice, while to say that there is also an ontological gap is to deny the possibility of any kind of reductionism. There are standard objections to this argument, that correspond to different materialistic positions: they are classified by Chalmers as Type A, Type B and Type C materialism. According to "Type A" materialism consciousness *is* functional. If Type A materialism is true, then we have entailment from the physical to the phenomenal and therefore we have reductive explanation of the mental in terms of the physical. Another popular answer to the arguments above is to accept that there is an epistemic gap but to deny that there is an ontological gap. This is what is called by Chalmers "Type B" materialism. According to this position, consciousness is not ontologically distinct from the physics. Conscious states are identical to physical or functional states, they are identities like "water = H_2O". They are not derived by analysis but they are discovered empirically, we have *a posteriori* identification. So there is an epistemic gap but not an ontological gap.

Notice that, even if a type B materialist would deny it, if type B materialism is true, we would have failure of reductive explanation of the mental in terms of the physical:

> Let us say that the property dualist is right about consciousness, and that consciousness is connected to the physical only by contingent laws. These laws might be inferred, in principle, from psychophysical regularities in the actual world. Given the presence of these laws, we can still arguably have some sort of explanation of consciousness and its properties, in terms of physical processes and the psychophysical laws. [...] But this will not be a case of reductive explanation, precisely because of the need for principles in our explanatory base over and above what is present in P. The laws themselves are not explained: they are epistemically primitive, in that they are not implied by more basic truths.[...] And these substantive, epistemically primitive principles play a central role in the explanation of the phenomena. So there is no transparent explanation of the phenomena in physical terms alone, and reductive explanation fails (Chalmers and Jackson 2001).

In other words, if type B materialism is true, P implies Q but it is not *a priori*. There are some identities that are not explained, they are epistemically primitive. Ontologically, this view is very similar to type A; while epistemically it is more similar to property dualism. In both cases, we do not have a clear explanation of consciousness.

Ontologically, these primitives could be different from laws, but epistemically they are the same. Calling them "bridge principles" or identities, one might continue to call himself a materialist but the explanatory structure is so far away from the one the materialist would hope for. One could insist that identities do not require explanation but this is a strange position to have: most of the time identities can and indeed are explained, like "water is H_2O". We come to know identities by deducing them, so that:

> If the identities in question were epistemically primitive, then explanations of the macroscopic phenomena in terms of microscopic phenomena would have a primitive "vertical" element, and science would have established a far weaker explanatory connection between the microscopic and the macroscopic than it actually has (Chalmers and Jackson 2001).

For completeness, let me mention the other strategy against the arguments abov, which is to claim that the epistemic gap is closable in principle. This is the position of "Type C" materialism, for example of Thomas Nagel and Colin McGinn. In this view, the unclosability of the gap is apparent, due to our limitations as humans. According to Nagel (Nagel 1974) we need conceptual revolution; according to McGinn (McGinn 1989) we will never be able to close this gap because humans do not, intrinsically, have the right concepts to grasp consciousness. So reductive explanation is possible in principle, but not in practice by us.

This discussion about the philosophy of mind is important for our purposes because if one wishes to insist on the wave function being the primitive ontology of quantum theories without observer, then one would have to solve the hard problem (the problem of explaining experiences) and the easy problem (the problem of explaining the behavior of physical objects in three-dimensional space) at once. Arguments with the same structure as those seen above can be written in the case of the wave function ontology to show that there cannot be reductive explanation of the macroscopic truths in terms of the truths expressed in the language of the wave function. For example, one could write an argument similar to the explanatory argument as follows:

1. The wave function accounts only for the world in configuration space,

2. Our experiences are of three-dimensional space so the wave function alone in configuration space is not enough to explain our experiences,

3. Therefore the wave function cannot explain the world, so wave function monism is false.

This argument shows that we need a rule to connect $\mathbb{R}^{3N}$ to $\mathbb{R}^3$. And, as for the case between physical and the phenomenal, between the wave function picture and the picture that comes to our senses, we have an epistemic gap from which we can infer an ontological gap:

1. There is an epistemic gap between P (the picture of the world provided by the wave function) and Q (the picture of the world provided by our experiences),

2. If there is an epistemic gap, there is an ontological gap,

3. Therefore, wave function monism is false.

If we recognize that there is an ontological gap, it would amount to considering the "links" discussed above as ontologies, not just pragmatic rules. As in the case of materialism, one could deny there is an epistemic gap (type A), one could accept there is this gap but deny that there is an ontological gap (type B or C). That is, people that hold the wave function ontology view and deny that we need anything more than that might be compared with the Type A materialist. A problem with this view is that it denies the obvious: as in the case of consciousness, there is something to be explained!

The view of those people like Albert, Loewer, Rimini, and Lewis discussed above seems to be close to type B materialism, since they recognize that there is something to explain (an epistemic gap) and this is because we need to add additional information to the one provided by the wave function, without giving to these rules of correspondence an ontological status. There is, as there is for type B materialism, one big worry for this view. Type B materialists claim that the perception of three-dimensional space is in the wave function in the same way that water is H_2O. Since the latter identity is *a posteriori*, so it is the former. But this analogy does not seem to be a good one: for example, there are not any epistemic arguments for water but there are for the wave function, as the argument above shows. In fact, there is no epistemic gap between water and H_20, given the complete physical description and the truth about water, while there is in the case of the wave function. The identity "water=H_20" is empirical but not primitive, since it can be deduced from the compete physical description. Type B materialists instead have to hold that the gap is primitive otherwise type A materialism would be true instead. The very same thing can be said also in the case of the wave function ontology: the rules of correspondence between wave function description and macroscopic description are *a posteriori* but not primitive. But what kind of identity is one in which there is an epistemic gap? This what is usually found in the laws of nature: to label these links identities and not laws might allow to maintain the label of materialism but this sacrifices most of the spirit of materialism or reductionism. One could insist that identities do not need explanation but in some cases they can be explained (like "water=H_2O") and so this suggests that all of them could and should be explained.

5.6 The Wave Function and Symmetry Properties

If the wave function is what quantum theories without observer are about, then they turn out not to have any symmetry property. Consider the case of Galilean invariance. There seems to be no good reason to justify any other transformation for the wave function under Galilean transformations other than that of a scalar field, given that, mathematically, it seems to be such an object. In other words, the transformation that one finds in physics books according to which the wave function transforms by multiplication of some strange exponential factor is simply unjustified. And if this is the case, that is, if the wave function transforms as a scalar field, then the Schrödinger's evolution is not Galilean invariant.

Here is the argument: Consider an N particles system evolving freely. The non relativistic Schrödinger equation is the law of the time evolution of a $N+1$-component scalar field ψ in three-dimensional space. It seems part of thinking of ψ as a concrete classical physical object to suppose that the way it transforms under a pure Galilean transformation of magnitude v is

$$\psi(q_1, ..., q_N, t) \to \psi(q_1 + vt, ..., q_N + vt, t), \tag{5.1}$$

and not

$$\psi(q_1, ..., q_N, t) \to \exp\left[\frac{i}{\hbar}\sum_{k=1}^{N} m_k\left(q_k \cdot v - \frac{1}{2}v^2 t\right)\right]\psi(q_1, ..., q_N, t), \tag{5.2}$$

as usually assumed. Note that if $\psi(q,t)$ is a solution to the free nonrelativistic Schrödinger equation, then $\psi(q+vt,t)$ is not. And so the corresponding Schrödinger equation (construed as a theory of the motions of a classical scalar field) is not invariant under Galilean transformations.

My first remark is that, the wave function in quantum mechanics is a ray or direction in Hilbert space. This means that the wave functions ψ and $c\psi$, where c is a non zero complex number, represent the same physical state. While if one believes that the wave function is part of the primitive ontology of the theory, then ψ is not defined up to a phase and it is indeed more like a scalar field. Let us suppose the transformation of a scalar field under Galilean transformation defined by equation (5.1) is the correct one. In the framework of a quantum theory of a primitive ontology in three-dimensional space, the wave function, as we saw in Chapter 4, is naturally a ray. The natural transformation of the ray under a Galilean transformation, since it is a projective object, can be determined by analyzing the projective representation of the Galilei group (see (Lévy-Leblond 1971)). There are five unitary and projective representations, among which only one is chosen to be the "natural" transformation, the one that leaves the physics the same. This transformation is exactly (5.2), the one that one finds in physics books. As a consequence the theory is Galilean invariant.

Since the wave function is a matter scalar field, the bare theories are not Galilean invariant. As a consequence, they provide the wrong results in the classical limit. Consider the example of a free particle on a line. Usually in ordinary quantum mechanics it is described by a wave packet. To simplify calculations, consider the case of a Gaussian wave packet. In taking the classical limit one should obtain results that are compatible with the Galilean invariance of classical mechanics. The point is that the transformation (5.1) gives the wrong results for the classical velocity, assuming that Newtonian mechanics is Galilean invariant. In order to obtain the correct result one has to adopt a different transformation, namely the transformation we find in physics books. Consider a (one dimensional) Gaussian wave packet centered in $x_0 = 0$ at time $t = 0$

$$\psi(q,0) = \frac{1}{(2\pi\sigma_0)^{1/4}} \exp\left[-\frac{q^2}{4\sigma_0^2} + i\frac{mu}{\hbar}q\right] \tag{5.3}$$

(Note that in the previous discussion we always had $\hbar = 1$ for convenience. Now, given that we will take the classical limit, we will have to reintroduce the parameter.) In the expression, σ_0 is the initial spreading of the packet and u is the velocity. At time t the packet has evolved to the form

$$\psi(q,t) = \frac{1}{\left[\sqrt{2\pi}\sigma_0\left(1+\frac{i\hbar t}{2m\sigma_0^2}\right)\right]^{1/2}} \exp\left[-\frac{(q-ut)^2}{4\sigma_0^2\left(1+\frac{i\hbar t}{2m\sigma_0^2}\right)} + i\frac{mu}{\hbar}\left(q-\frac{u}{2}t\right)\right] \tag{5.4}$$

We can write it as

$$\psi(q,t) = R(q,t)\mathrm{e}^{\frac{i}{\hbar}S(q,t)}, \tag{5.5}$$

where S is given by

$$S(q,t) = muq - \frac{1}{2}mu^2t + \frac{1}{2}\left(\frac{\hbar t}{2m\sigma_0^2}\right)^2 \frac{(q-ut)^2\frac{m}{t}}{1+\left(\frac{\hbar t}{2m\sigma_0^2}\right)^2} \tag{5.6}$$

and R by

$$R(q,t) = \frac{1}{\left[\sqrt{2\pi}\sigma_0\left(1+\frac{i\hbar t}{2m\sigma_0^2}\right)\right]^{1/2}} \exp\left\{-\frac{(q-ut)^2}{4\sigma_0^2\left(1+\left[\frac{\hbar t}{2m\sigma_0^2}\right]^2\right)}\right\}. \tag{5.7}$$

According to the general formulation of the classical limit in the framework of orthodox quantum mechanics (Maslov 1981), the classical velocity associated to the particle is given by

$$V = \frac{\nabla S^0}{m}, \tag{5.8}$$

where S^0 is obtained by S in the limit "$\hbar \to 0$"[2]. In the case of a free Gaussian wave

[2]This limit should be intended as the mathematical implementation of considering a situation in which the relevant action of the system is big compared to $\hbar$.

packet, we have

$$S^0(q,t) = muq - \frac{1}{2}mu^2t + O(\hbar^2), \tag{5.9}$$

and therefore

$$V = u. \tag{5.10}$$

If this is the velocity of the particle associated to the packet in the classical limit, we should expect that it would transform under a pure Galilean transformation $g = (0, 0, v, 1)$ (in one spatial dimension) of velocity v corresponding to $V \rightarrow V + v$, since classical mechanics is Galielan invariant. This is not the case if the wave function transforms according to (5.1). In fact suppose that under the transformation $x \rightarrow q + vt$ the wave function transforms as $\psi(q,t) \rightarrow \psi(q + vt)$. Then, the action S will transform as

$$S(q,t) \rightarrow S(q + vt, t) \tag{5.11}$$

where $S(q + vt)$ is

$$S(q + vt, t) = muq - \frac{1}{2}mu^2t + \frac{1}{2}\left(\frac{\hbar t}{2m\sigma_0^2}\right)^2 \frac{[q - (u - v)t]^2 \frac{m}{t}}{1 + \left(\frac{\hbar t}{2m\sigma_0^2}\right)^2}. \tag{5.12}$$

In the classical limit it becomes (up to a factor $O(\hbar^2)$)

$$S^0(q + vt, t) = muq - \frac{1}{2}mu^2 \tag{5.13}$$

that is , V is

$$V = u, \tag{5.14}$$

that is not the expected result $u + v$.

In contrast, suppose the wave function transforms under a pure one dimensional Galilean transformation according to

$$\psi(q,t) \rightarrow \exp\left[\frac{i}{\hbar}\left(mvq + \frac{1}{2}mv^2t\right)\right]\psi(q,t). \tag{5.15}$$

We can see that with that transformation the correct classical limit is now obtained.

In fact the action S transforms as

$$S(q,t) \to m(u+v)q - \frac{m}{2}\left(u^2 - v^2\right)t + \frac{1}{2}\left(\frac{\hbar t}{2m\sigma_0^2}\right)^2 \frac{(q-ut)^2 \frac{m}{t}}{1+\left(\frac{\hbar t}{2m\sigma_0^2}\right)^2}. \qquad (5.16)$$

that gives in the classical limit (up to a factor $O(\hbar^2)$)

$$S^0(q,t) = m(u+v)q - \frac{m}{2}\left(u^2 + v^2\right)t \qquad (5.17)$$

and therefore

$$V = u + v \qquad (5.18)$$

as it is expected.