

Framework for Possible Unification of Quantum and Relativity Theories

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We put forward a framework, inspired by recent axiomatic and operational approaches to generalized quantum theories, wherein we investigate the possibility of unifying quantum and relativity theories. The framework concentrates on a detailed analysis of a general construction of reality that can be used in both quantum and relativity theories. By means of this construction of reality we clarify some well-known conceptual problems that stand in the way of a conceptual unification of quantum and relativity theories on a more profound physical level than the purely mathematical algebraic level on which unification attempts are generally investigated. More specifically we concentrate on the problem of "what is physical reality" in quantum and relativity theories.

1. INTRODUCTION

Nowadays physics is rooted in two well-established physical theories: quantum theory and relativity theory. There have been several attempts to unify quantum theory with relativity theory, but they have been only partially successful: quantum electrodynamics, for example, is a well-defined physical theory describing the interaction between light and matter and its theoretical predictions correspond to a very high degree with the experimental results. Other attempts have encountered conceptual as well as technical difficulties, such that it can be stated that the program of unifying quantum theory with relativity theory is unfinished. In this paper we put forward a framework that could be used to investigate a new approach to unification. Before we introduce the framework, let us first briefly explain our motivation.

There are two aspects that make a unification attempt in our framework different from the traditional approaches. The first is connected to the fact

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that our framework is inspired by the generalized quantum theories that have been developed during the last decades rather than by the standard Hilbert space quantum theory, which is the inspiration of the classical unification attempts. Standard quantum theory is a well-defined mathematical theory, where the state of an entity is represented by a vector ψ in a complex Hilbert space and a quantity by a self-adjoint linear operator A of this Hilbert space. The contact with experimental data is given by the rule that the probability that the value of the observable quantity A is in an interval a when the state of the quantum entity is ψ is given by $|\langle \psi, P_a \psi \rangle|^2$, where P_a is the spectral projection of the operator A corresponding to the interval a . The ontological basis of the standard quantum-theoretic scheme is very badly defined. The actual unification attempts (e.g., quantum field theories) are attempts to unify quantum theory and relativity theory starting from this standard quantum-theoretic scheme and forcing the relativistic aspects of the theory onto the structure of the algebra of operators that represent the observable quantities. For standard quantum theory there is no clear meaning for the basic concepts and hence it is not possible to reflect on a unification on a physically deeper level than the purely mathematical algebraic level. For relativity theory, the ontological basis was clearly introduced from the beginning in a very careful and general way. Meanwhile, due to new experiments on individual quantum entities and new theoretical considerations, the ontological basis of quantum theory has been greatly clarified. Inspired by early generalizations (Birkhoff and von Neumann, 1936; Jauch, 1968), axiomatic approaches have been developed where the concepts are introduced more and more in an operational way (Aerts, 1981, 1982, 1983a,b, 1986, 1990, 1992, 1994, 1995; Gudder, 1988; Piron, 1976, 1985, 1988, 1990; Randall and Foulis, 1979, 1983). The framework that we present here is inspired by these operational approaches, and more specifically by the realistic approaches (Aerts, 1981, 1982, 1983a,b, 1990, 1992; Piron, 1976, 1985, 1988, 1990).

The second aspect that makes our framework especially suited for a new attempt at unification is of a conceptual nature. Although we have given the impression in the foregoing paragraph that the ontological basis of relativity theory is well defined, we must remark that in both theories, quantum mechanics as well as relativity theory, it is not clear "what reality is." Therefore in our framework we start by a subtle analysis of the nature of reality.

In quantum theory the problem about the question "what is the reality of a quantum entity" presents itself in the following way. Suppose that we consider a quantum entity S in a state ψ . This state can mathematically be represented by a wave function $\psi(x_1, x_2, x_3)$ that is an element of the complex Hilbert space $L^2(R^3)$ of square-integrable complex functions. When a measurement of position is performed on this quantum entity in state ψ , no prediction

with certainty can be given of where the quantum entity will be detected. More specifically, the probability that the quantum entity will be located in a region Ω of space is given by $\int_{\Omega} |\psi(x_1, x_2, x_3)|^2 dx_1 dx_2 dx_3$, and this is a number between 0 and 1, since $\int_{R^3} |\psi(x_1, x_2, x_3)|^2 dx_1 dx_2 dx_3 = 1$. If we consider a measurement of the momentum of the same quantum entity S in the same state ψ , then we find a very similar situation. The same state ψ can also be represented by the wave function $\psi(p_1, p_2, p_3)$ in momentum space, again an element of the complex Hilbert space $L^2(R^3)$ of square-integrable complex functions, and $\psi(p_1, p_2, p_3)$ is the Fourier transform of $\psi(x_1, x_2, x_3)$. The probability that the momentum of the quantum entity is contained in the momentum region P is given by $\int_P |\psi(p_1, p_2, p_3)|^2 dp_1 dp_2 dp_3$, where again $\int_{R^3} |\psi(p_1, p_2, p_3)|^2 dp_1 dp_2 dp_3 = 1$. This means that for a quantum entity in state ψ neither the position nor the momentum can be predicted with certainty. This situation has been confirmed by so many experiments on quantum entities that it is now commonly accepted as a fact of nature. As a consequence the question “what is the reality of a quantum entity?” has no obvious answer. This problem has been in debate for more than 60 years now. It would be too conclusive to say that the problem has been solved, but some fruitful solutions with a clearly defined ontological basis have been put forward. Each of these solutions incorporates “not being localized” and “not having a definite momentum” as a “real effect” on the ontological level (Aerts 1990, 1992, 1994, 1995). Therefore in the framework that we present here the quantum entity in state ψ is considered to “not have a definite position” and “not have a definite momentum” when it is in a state ψ . When a detection takes place then the “place” of the quantum entity is partly created by the detection apparatus, and when a measurement of momentum takes place the “momentum” of the quantum entity is partly created by this momentum measurement. We have explained in detail this ontological basis for quantum theory in Aerts (1990, 1992, 1994, 1995), and have called it the “creation discovery interpretation.”

Let us now consider relativity theory. Perhaps it is less well known that there are also problems with the question “what is reality?” concerning relativity theory. The problem with this question manifests itself here in a completely different way. Usually relativity theory is introduced with a seemingly very well defined ontological basis (e.g., Misner *et al.*, 1993). The collection of events, each event parametrized by four real numbers (x_0, x_1, x_2, x_3) , is considered to be the basic structure of the theory. For a particular observer connected to a particular reference frame, there is no problem of how to use this four-dimensional time-space manifold scheme to decide what his or her “personal reality” is. This personal reality is indeed the “space-cut” that the observer’s reference frame makes with the four dimensional time-space manifold. This space-cut only determines a reality that is connected

to this particular reference frame, and at first sight it is not possible to put together the space-cuts of different reference frames such that they form one reality. All this is very well known, and this problem was in fact already at the origin of the construction of special relativity in the original paper by Albert Einstein, namely his critique of the concept of simultaneity (Einstein, 1905). When Einstein elaborated special relativity, he was a firm believer in an operational approach, and that is certainly part of the reason why the conceptual foundation of relativity theory is very well operationally founded. As we shall see in the next section, with the introduction of our framework it follows that “simultaneity” as considered by Einstein is not a good concept for defining “reality.” Reality should not be defined as “all that happens simultaneously.” We believe that this conceptual mistake concerning the definition of reality is at the origin of the problems with the ontological basis for relativity theory.

Sometimes it is rather vaguely stated, and these statements are never conceptually founded, that reality in relativity theory “is” the four-dimensional time-space continuum. But if this position is taken, there is another major conceptual problem: indeed then there is no change and no evolution in time. This makes quantum theory, which fundamentally is a theory of evolution in time, completely irreconcilable with relativity theory.

As we see, there are many conceptual as well as structural aspects that we have to clarify even before we can start to work out our general framework in a technical way. In the next section we shall introduce the foundations of our general framework and step by step refer to the way in which it allows us to tackle problems such as some of those mentioned in this introduction.

2. THE CONSTRUCTION OF REALITY

The foundations of the framework that we put forward here can be found in Aerts (1992). To make the paper self-contained we will repeat most of the basic definitions. First we analyze the “construction of reality.” This analysis might give the impression that we adhere to a subjective philosophy, believing perhaps that reality is “only” a construction of the human mind. This is not true; we believe that reality exists, independent of the presence of humans to participate in it. We want to put forward this analysis of our human construction of reality because we think that only by understanding all the subtle steps of this construction can we understand the question “what is reality?” in relation to quantum physics and relativity theory.

2.1. Experiences

The basic concept of our approach is that of an experience. An experience is an interaction between a participator² and a piece of the world. When the participator lives such an experience, we will say that this experience is *present*, and we will call it the *present experience* of the participator. When we consider a measurement, then we conceive this situation as the experimenter and the experimental apparatus together being the participator, and the physical entity under study to be the piece of the world that interacts with the participator. The experiment is the experience.

Let us give some examples of experiences. Consider the following situation: I am inside my house in Brussels. It is night, the windows are shut. I sit in a chair, reading a novel. I have a basket filled with walnuts at my side, and from time to time I take one of them, crack it, and eat it. My son is in bed and already asleep. New York exists and is busy.

Let us enumerate the experiences that are considered in such a situation:

- (1) E_1 (I read a novel).
- (2) E_2 (I experience the inside of my house in Brussels).
- (3) E_3 (I experience that it is night).
- (4) E_4 (I take a walnut, crack it, and eat it).
- (5) E_5 (I see that my son is in bed and asleep).
- (6) E_6 (I experience that New York is busy).

The first very important remark I want to make is that obviously I do not experience all these experiences at once. On the contrary, in principle, I only experience one experience at once, namely my present experience. Let us suppose that my present experience is E_1 (I read a novel). Then a lot of other things happen while I am living this present experience. These things happen in my present reality. While "I am reading the novel" some of the happenings that happen are the following: H_1 (the novel exists), H_2 (the inside of my house in Brussels exists), H_3 (it is night), H_4 (the basket and the walnuts exist, and are at my side), H_5 (my son is in bed and is sleeping), H_6 (New York exists and is busy). All the happenings, and much more, happen while I live the present experience E_1 (I read a novel).

Why have I constructed reality in such a way that what I am just saying is evident for everybody (and therefore shows that we are not conscious of the construction that is behind this evidence)?

Certainly it is not because I experience also these other happenings. My only *present* experience is the experience of reading the novel. But, and this is the reason for this type of construction, I could have chosen to live an

²We use the word "participator" instead of the word "observer," to indicate that we consider the cognitive receiver to participate creatively in his or her cognitive act.

experience including one of the other happenings *in replacement* of my present experience. Let me put down the list of these experiences that I could have chosen to experience in replacement of my present experience: E_2 (I observe that I am inside my house in Brussels), E_3 (I see that it is night), E_4 (I take a walnut, crack it, and eat it), E_5 (I go and look in the bedroom to see that my son is asleep), E_6 (I go to New York and see that it is busy).

This example indicates how we have started to construct reality. First of all we have tried to identify two main aspects of an experience. The aspect that is controlled and created by me, and the aspect that just happens to me and can only be known by me. Let us introduce this important distinction in a formal way.

2.2. Creations and Happenings

To see what I mean, let us consider the experience E_4 (I take a walnut, crack it, and eat it). In this experience, there is an aspect that is an action of mine, the taking and the cracking, and the eating. There is also an aspect that is an observation of mine, the walnut and the basket. By studying how our senses work, I can indeed say that it is the light reflected on the walnut, and on the basket, that gives me the experience of walnut and the experience of basket. This is an explanation that only now can be given; it is, however, not what was known in earlier days when the first world models of humanity were constructed. But without knowing the explanation delivered now by a detailed analysis, we could see very easily that an experience contains always two aspects, a *creation*-aspect, and an *observation*-aspect, simply because our will can only control part of the experience. This is the creation-aspect.

For example, in E_1 (I read a novel) the reading is created by me, but the novel is not created by me. In general we can indicate for an experience the aspect that is created by me and the aspect that is not created by me. The aspect not created by me lends itself to my creation. We can reformulate an experience in the following way: E_4 (I take a walnut, crack it, and eat it) becomes E_4 (The walnut is taken by me, and lends itself to my cracking and eating) and E_1 (I read a novel) becomes E_1 (The novel lends itself to my reading).

The taking, cracking, eating, and reading will be called *creations* or actions and will be denoted by C_4 (I take, crack, and eat) and C_1 (I read). The walnut and the novel will be called *happenings* and will be denoted by H_4 (The walnut) and H_7 (The novel).

A creation is that aspect of an experience created, controlled, and acted by me, and a happening is that aspect of an experience lending itself to my creation, control, and action.

An experience is determined by a description of the creation and a description of the happening. Creations are often expressed by verbs: to take, to crack, to eat, and to read are the verbs that describe my creations in the examples. The walnut and the novel are happenings that have the additional property of being objects, which means happening with a great stability. Often happenings are expressed by a substantive.

Every one of my experiences E consists of one of my creations C and one of my happenings H , so we can write $E = (C, H)$.

A beautiful image that can be used as a metaphor for our model of the world is the image of the skier. A skier skis downhill. At every instant he or she has to be in complete harmony with the form of the mountain underneath. The mountain is the happening. The actions of the skier are the creation. The skier's creation, in harmony fused with the skier's happening, is his or her experience.

2.3. The Construction of Reality, Present, Past, and Future

Let us again consider the collection of experiences: E_1 (I read a novel), E_2 (I observe that I am inside my house in Brussels), E_3 (I see that it is night), E_4 (I take a walnut, crack it, and eat it), E_5 (I go and look in the bedroom to see that my son is asleep), and E_6 (I go to New York and see that it is busy). Let us now represent the "construction of reality" that is made out of this little collection of experiences.

E_1 (I read a novel) is my present experience. In my past I could, however, at several moments have chosen to do something else and this choice would have led me to have another present experience than E_1 (I read a novel). For example:

One minute ago I could have decided to stop reading and observe that I am inside the house. Then E_2 (I observe that I am inside my house in Brussels) would have been my present experience.

Two minutes ago I could have decided to stop reading and open the windows and see that it is night. Then E_3 (I see that it is night) would have been my present experience.

Three minutes ago I could have decided to stop reading, take a walnut from the basket, crack it, and eat it. Then E_4 (I take a walnut, crack it, and eat it) would have been my present experience.

Ten minutes ago I could have decided to go and see in the bedroom whether my son is asleep. Then E_5 (I go and look in the bedroom to see that my son is asleep) would have been my present experience.

Ten hours ago I would have decided to take the plane and fly to New York and see how busy it was. Then E_6 (I go to New York and see that it is busy) would have been my present experience.

Even when they are not the happening aspect of my present experience, happenings "happen" at present if they are happening aspect of an experience that I could have lived in replacement of my present experience, if I would have decided so in my past.

The fact that a certain experience E consisting of a creation C and a happening H is for me a possible present experience depends on two factors:

- (1) I have to be able to perform the creation.
- (2) The happening has to be available.

For example, the experience E_2 (I observe that I am inside my house in Brussels) is a possible experience for me if:

- (1) I can perform the creation that consists in observing the inside of my house in Brussels. In other words, if this creation is in my personal power.
- (2) The happening "the inside of my house in Brussels" has to be available to me. In other words, this happening has to be contained in my personal reality.

The collection of all creations that I can perform at the present I will call my present personal power.

The collection of all happenings that are available to me at the present I will call my present personal reality.

I define as my present personal reality the collection of these happenings, the collection of happenings that are available to one of my creation if I would have used my personal power in such a way that at the present I fuse one of these creations with one of these happenings.

My present personal reality consists of all happenings that are available to me at present. My past reality consists of all happenings that were available to me in the past. My future reality consists of all happenings that shall be available to me in the future.

My present personal power consists of all creations that I can perform at present. My past personal power consists of all the creations that I could perform in the past. My future personal power consists of all creations I shall be able to perform in the future.

Happenings can happen at once, because to happen, a happening does not have to be part of my present experience. It is sufficient that it is available, and things can be available at once. Therefore, although my present experience is only one, my present personal reality consists of an enormous amount of happenings all happening at once.

This concept of reality is not clearly understood in present physical theories. Physical theories know how to treat past, present, and future. But

reality is a construction about the possible. It is a construction about the experiences I could have lived but probably will never live.

2.4. Material Time and Material Happenings

From ancient times humanity has been fascinated by happenings going on in the sky, the motion of the sun, the changes of the moon, the motions of the planets and the stars. These happenings in the sky are *periodic*. By means of these periodic happenings humans started to *coordinate* the other experiences. They introduced the counting of the years, the months, and the days. Later watches were invented to be able to coordinate experiences of the same day. And in this sense *material* time was introduced into the reality of the human species. Again we want to analyze the way in which this material time was introduced, to be able to use it operationally when we analyze the paradoxes of time and space.

My present experience is seldom a material time experience. But in replacement of my present experience, I always could have consulted my watch, and in this way live a material time experience E_7 (I consult my watch and read the time). In this way, although my present experience is seldom a material time experience, my present reality always contains a material time happening, namely the happening H_7 (The time indicated by my watch), which is the happening to which the creation C_7 (I consult) is fused to form the experience E_7 .

We can try to use our theory for a more concrete description of that layer of reality that we shall refer to as the layer of “material or energetic happenings.” We must be aware of the fact that this layer is a huge one, and so first of all we shall concentrate on those happenings that are related to the interactions between what we call material (more generally energetic) entities. We have to analyze first of all in which way the four-dimensional manifold that generally is referred to as the “time-space” of general relativity theory is related to this layer of material or energetic reality. We shall take into account in this analysis the knowledge that we have gathered about the reality of the quantum entities in relation with measurements of momentum and position.

3. QUANTUM, RELATIVITY, AND REALITY

We consider the set of all material or energetic happenings and denote this set by \mathcal{M} . Happenings of \mathcal{M} we shall denote by m, n, o . Let us consider such a happening m that corresponds to a quantum entity. Then this happening is characterized by the fact that it is always available to a creation of localization (consisting of localizing the particle in a certain region of space); let us

denote such a creation of localization by l . Then the experience (l, m) is an experience that can be coordinated by a certain point (x_0, x_1, x_2, x_3) of the four-dimensional manifold that is referred to as time-space.

However, instead of performing a creation of localization, one can choose to perform a creation that consists in measuring the momentum of the quantum entity. Let us denote this creation by i ; then the happening (i, m) can be coordinated by a certain point (p_0, p_1, p_2, p_3) , which can be interpreted by the four-momentum of general relativity theory.

We know from quantum theory that the quantum entity can be in different states, that they all correspond to a different statistics as related to repeated localizations and measurements of momentum. Let us denote these states by q, p, \dots . The quantum entity can be in an eigenstate $q(x_0, x_1, x_2, x_3)$ of position, which means that the creation of localization in this eigenstate leads with certainty to a finding of the quantum entity in the point (x_0, x_1, x_2, x_3) . The quantum entity can also be in an eigenstate $p(p_0, p_1, p_2, p_3)$ of momentum, which means that by a measurement of momentum the entity will be found to have the momentum (p_0, p_1, p_2, p_3) . But in general the quantum entity will be in a state that is neither an eigenstate of position nor an eigenstate of momentum. It is only after the happening p (the state of the quantum entity) has been fused with one of the creations l (the localization measurement) or i (the momentum measurement) that it will be in an eigenstate of localization (a point of time-space) or of momentum (a point of four-momentum space). This is the general situation for material happenings.

3.1. The Construction of Reality and Relativity

To show the problems that we can solve by means of our framework, we will concentrate now on the question “what is reality in relativity theory?” Since we have an operational definition of reality in our framework, we can investigate this problem in a rigorous way.

Let us suppose that I am here now in my house in Brussels, and it is June 1, 1996, 3 pm exactly. I want to find out “what is the material reality for me now?” Let us use the definition of reality given in the foregoing section and consider a place in New York, for example, at the entrance of the Empire State building, and let us denote this place, the center of this place, for example, by (x_1, x_2, x_3) . I also choose now a certain time, for example, June 1, 1996, 3 pm exactly, and let me denote this time by x_0 . I denote the happening that corresponds with the spot (x_1, x_2, x_3) located at the entrance of the Empire State building, at time x_0 by m . I can now try to investigate whether this happening m is part of my personal material reality. The question I have to answer is, can I find a creation of localization l —in this case this creation is just the observation of the spot (x_1, x_2, x_3) at the

entrance of the Empire State building, at time x_0 —that can be fused with this happening m ? The answer to this question can only be investigated if we take into account the fact that I, who wants to try to fuse a creation of localization to this happening, am bound to my body, which is also a material entity. I must specify the question by introducing the material time coordinate that I coordinate by my watch. So suppose that I coordinate my body by the four numbers (y_0, y_1, y_2, y_3) , where y_0 is my material time, and (y_1, y_2, y_3) is the center of mass of my body. We apply now our operational definition of reality. At this moment, June 1, 1996 at 3 pm exactly, my body is in my house in Brussels, which means that (y_0, y_1, y_2, y_3) is a point such that y_0 equals June 1, 1996, 3 pm, and (x_1, x_2, x_3) is a point, the center of mass of my body, somewhere in my house in Brussels. This shows that (x_0, x_1, x_2, x_3) is different from (y_0, y_1, y_2, y_3) , in the sense that (x_1, x_2, x_3) is different from (y_1, y_2, y_3) , while $x_0 = y_0$.

The question is now whether (x_0, x_1, x_2, x_3) is a point of my material reality, hence whether it makes sense to me to claim that now, June 1, 1996, 3 pm, the entrance of the Empire State building “exists.” If our theoretical framework corresponds in some way to our prescientific construction of reality, the answer to the foregoing question should be affirmative. Indeed, we all believe that “now” the entrance of the Empire State building exists. Let us try to investigate in a rigorous way this question in our framework. We have to verify whether it was possible for me to decide somewhere in my past, hence before June 1, 1996, 3 pm, to change some of my plans of action, such that I would decide to travel to New York, and arrive exactly at June 1, 1996, 3 pm, at the entrance of the Empire State building, and observe the spot (x_1, x_2, x_3) . We could give many concrete ways to realize this experiment, and we will not give here one in detail, because we shall come back to the tricky parts of the realization of this experiment in the following example. But hence the answer is indeed affirmative: I could have experienced the spot (x_1, x_2, x_3) at June 1, 1996, 3 pm, if I had decided to travel to New York somewhere in my past. Hence (x_0, x_1, x_2, x_3) is part of my reality. It is sound to claim that the entrance of the Empire State building exists right now. And we remark that this does not mean that I have to be able to experience this spot at the entrance of the Empire State building now, June 1, 1996, 3 pm, while I am inside my house in Brussels. I repeat again, reality is a construction about the possible happenings that I could have fused with my actual creation. And since I could have decided so in my past, I could have been at the entrance of the Empire State building, now, June 1, 1996, 3 pm.

Up to this point we could think that our framework only will confirm our intuitive notion of reality, but our next example shows that this is certainly not the case. Indeed, let me consider the same problem, but now consider

another point of time-space. I consider the point (z_0, z_1, z_2, z_3) , where $(z_1, z_2, z_3) = (x_1, x_2, x_3)$, hence the spot we envisage is again the entrance of the Empire State building, and z_0 is June 2, 1996, 3 pm exactly, hence the time that we consider is tomorrow 3 pm. If I ask now first, before checking rigorously by means of our operational definition of reality, whether this point (z_0, z_1, z_2, z_3) is part of my present material reality, the intuitive answer here would be "no." Indeed, tomorrow at the same time, 3 pm, is in the future and not in the present, and hence it is not real, and hence no part of my present material reality (this is the intuitive reasoning). If we go now to the formal reasoning in our framework, then we can see that the answer to this question depends on the interpretation of relativity theory that we put forward. Indeed, let us first analyze the question in a Newtonian conception of the world to make things clear. Remark that in a Newtonian conception of the world (which has been proved experimentally wrong, so here we are just considering it for the sake of clarity), my present material reality just falls together with "the present," namely all the points of space that have the same time coordinate June 1, 1996, 3 pm. This means that the entrance of the Empire State building tomorrow "is not part of my present material reality." The answer is clear here and in this Newtonian conception, my present personal reality is just the collection of all (u_0, u_1, u_2, u_3) , where $u_0 = y_0$ and (u_1, u_2, u_3) are arbitrary. The world is not Newtonian, this we know meanwhile experimentally, but also if we put forward an Aether theory interpretation of relativity theory (let us refer to such an interpretation as a Lorentz interpretation), the answer remains the same. In a Lorentz interpretation, my present personal reality coincides with the present reality of the Aether, namely all arbitrary points of the Aether that are at time y_0 , June 1, 1996, 3 pm, and again tomorrow the entrance of the Empire State building is not part of my present material reality.

For an Einsteinian interpretation of relativity theory the answer is different. To investigate this I have to ask again the question of whether it would have been possible for me to decide in my past such that I would have been able to make (y_0, y_1, y_2, y_3) coincide with (z_0, z_1, z_2, z_3) . The answer here is that this is very easy to do, because of the well-known, and experimentally verified, effect of "time dilatation." Indeed, it would, for example, be sufficient that I go back some weeks in my past, let us say April 1, 1996, 3 pm, and then decide to step inside a space ship that can move with almost the speed of light, such that the time when I am inside this space ship slows down in such a way that when I return with the space ship to the earth, still flying with a speed near the velocity of light, I arrive in New York at the entrance of the Empire State building while my personal material watch indicates June 1, 1996, 3 pm, and the watch that remained at the entrance of the Empire State building indicates June 2, 1996, 3 pm. Hence in this way I make

(y_0, y_1, y_2, y_3) coincide with (z_0, z_1, z_2, z_3) , which proves that (z_0, z_1, z_2, z_3) is part of my present material reality. First I have to remark that in practice it is not yet possible to make such a flight with a space ship such as the one that I put forward in this reasoning. But this is not a crucial point for our reasoning. It is sufficient that we can do it in principle.³

3.2. Einstein versus Lorentz: Does Reality Have Four Dimensions?

We can come now to one of the points that we want to make in this paper, and that clarifies the paradox of time that makes the difference between an Aether interpretation of relativity (Lorentz) and an Einsteinian interpretation of relativity. Why would we come to a different result concerning the foregoing question, depending on whether we advocate an Einsteinian interpretation of relativity theory or an Aether interpretation? To clarify this we have to come back to the essential aspect of the construction of reality in our framework, which is the difference between a creation and a happening. We have to give first another example to clarify what we mean.

Suppose that I am a painter and I consider again my present material reality, at June 1, 1996, 3 pm, as indicated on my personal material watch. I am in my house in Brussels, as we said before, and let us specify: the room where I am is my workshop, surrounded by paintings, of which some are finished and others I am still working on. Clearly all these paintings exist in my present reality, June 1, 1996, 3 pm. Some weeks ago, when I was still working on a painting that now is finished, I could certainly have decided to start to work on another painting, a completely different one, that now does not exist. Even if I could have decided this some weeks ago, everyone will agree that this other painting that I never started to work on does not exist now, June 1, 1996, 3 pm. The reason for this conclusion is that the making of a painting is a “creation” and not a happening. It is not so that there is some “hidden” space of possible paintings such that my choice of some weeks ago to realize this other painting would have made me to detect it. If this would be the situation with paintings, then indeed also this painting would exist now, in this hidden space. But with paintings this is not the case. Paintings that are not realized by the painter are potential paintings, but they do not exist.

³We have not yet made this explicit remark, but obviously if we have introduced in our framework an operational definition for reality, then we do not have to interpret such an operational definition in the sense that only operations are allowed that actually, taking into account the present technical possibilities of humanity, can be performed. If we would advocate such a narrow interpretation, then even in a Newtonian conception of the world, the star Sirius would not exist, because we cannot yet travel to it. What we mean by operational is much wider. It must be possible, taking into account the actual physical knowledge of the world, to conceive of a creation that can be fused with the happening in question, and then this happening pertains to our personal reality.

With this example of the paintings we can explain very well the difference between Lorentz and Einstein. For an Aether interpretation of relativity the fact that my watch is slowing down while I decide to fly with the space ship nearly at the speed of light and return at the entrance of the Empire State building while my watch is indicating June 1, 1996, 3 pm, and the watch that remained at the Empire State building indicates June 2, 1996, 3 pm, is interpreted as a "creation." It is seen as if there is a real physical effect of creation on the material functioning of my watch while I travel with the space ship, and this effect of creation is generated by the movement of the space ship through the Aether. Hence the fact that I could observe the entrance of the Empire State building tomorrow June 2, 1996, 3 pm, when I would have decided some weeks ago to start traveling with the space ship, only proves that the entrance of the Empire State building tomorrow is a potentiality, just like the fact that this painting that I never started to paint could have been here in my workshop in Brussels is a potentiality. This means that as a consequence the spot at the entrance of the Empire State building tomorrow is not part of my present reality, just as the possible painting that I did not start to paint is not part of my present reality. If we, however, put forward an Einsteinian interpretation of relativity, then the effect on my watch during the space ship travel is interpreted in a completely different way. There is no physical effect on the material functioning of the watch,⁴ but the flight at the velocity nearly the speed of light "moves" my space ship in the time-space continuum such that time coordinates and space coordinates get mixed. This means that the effect of the space ship travel is an effect of a voyage through the time-space continuum, which brings me at my personal time of June 1, 1996, 3 pm, at the entrance of the Empire State building, where the time is June 2, 1996, 3 pm. And hence the entrance of the Empire State building is a happening, an actuality and not just a potentiality, and it can be fused with my present creation. This means that the happening (z_0, z_1, z_2, z_3) of June 2, 1996, 3 pm, entrance of the Empire State building, is a happening that can be fused with my creation of observation of the spot around me at June 1, 1996, 3 pm. Hence it is part of my present material reality. The entrance of the Empire State building at June 2, 1996, 3 pm, exists for me today, June 1, 1996, 3 pm.

If we advocate an Einsteinian interpretation of relativity theory we have to conclude from the foregoing section that reality is four-dimensional. This conclusion will perhaps not amaze those who always have considered the time-space continuum of relativity as representing reality. Now that we have

⁴Certainly if we take into account that most of the time dilatation takes place not during the accelerations that the space ship undergoes during the trip, but during the long periods of flight with constant velocity nearly at the speed of light.

defined very clearly the meaning of this, we can start to investigate the seemingly paradoxical conclusions that often are brought forward in relation with this insight.

3.3. The Process View Confronted with the Geometric View

The paradoxical situation which we can see now is the confrontation of the process view of reality with the geometric view. Often it is claimed that an interpretation where reality is considered to be related to the four-dimensional time-space continuum contradicts another view of reality, namely the one where it is considered to be of a process-like nature. By means of our framework we can now understand exactly these two views and see that there is no contradiction. Let us repeat now the meaning in our framework of the conclusion that reality is four-dimensional. It means that, at a certain specific moment that I call my "present," the collection of places that exist, and that I could have observed when had I decided to do so in my past, has a four-dimensional structure, well represented mathematically by the four-dimensional time-space continuum. This is indeed my present material reality. This does not imply, however, that this reality is not constantly changing. Indeed it is constantly changing. New entities are created in it while other entities disappear, and while others are very stable and remain in existence. This is equally the case in all of the four dimensions of this reality. Again I give an example to explain what I mean. When we came to the conclusion that now, at June 1, 1996, 3 pm, the entrance of the Empire State building exists for me while I am in my house in Brussels, this is not a statement of deterministic certainty. Indeed, it is well possible that by some extraordinary chain of events, without me knowing about these events, the Empire State building had been destroyed, such that my statement about the existence of the entrance of the Empire State building "now," although almost certainly true, is not deterministically certain. The reason is again the same, namely that reality is a construction of what I would have been able to experience if I had decided differently in my past. The knowledge that I have about this reality is complex and depends on the changes that go on continuously in it. What I know from experience is that there do exist material objects, and the Empire State building is one of them, that are rather stable, which means that they are in existence without changing too much. To these stable objects, material objects but also energetic fields, I can attach the places where I could observe them. The set of these places has the structure of a four-dimensional continuum. That is all. At the same time all these objects are continuously changing and moving in this four-dimensional scenery. Most of the objects that I use to shape my intuitive model of reality are the material objects that surround us here on the surface of the earth. They all are very

fixed in the fourth dimension (the dimension indicated by the 0 index, and we should not call it the time dimension), while they move easily in the other three dimensions (those indicated by the 1, 2, and 3 indexes). Other objects, for example, electromagnetic fields, have a completely different way of being and changing in this four-dimensional scenery. This means that in our framework there is no contradiction between the four-dimensionality of the set of places and the process-like nature of the world. If we came to the conclusion that the entrance of the Empire State building, tomorrow, June 2, 1996, 3 pm, exists also for me now, then our intuition reacts more strongly to this statement, because intuitively we think that this would mean that the future exists also and hence is determined and hence no change is possible. This is a wrong conclusion which comes from the fact that during a long period of time we have had an intuitive image of a Newtonian present that would be determined completely. We have to be aware of the fact that it is the present, even in the Newtonian sense, which is not determined at all. We can only say that the more stable entities in my present reality are more determined to be there, while the places where they can be, because these places are stable with certainty, are always there.

3.4. The Singularity of the Reality Construction

We want to come back to the construction of reality in our framework that we have confronted here with the Einsteinian interpretation of relativity theory. Instead of wondering about the existence of the entrance of the Empire State building tomorrow, June 2, 1996, 3 pm, I can also question the existence of my own house at the same place of the time-space continuum. Clearly I can make an analogous reasoning and come then to the conclusion that my own house, and the chair where I am sitting while reading the novel, and the novel itself, and the basket of walnuts beside me, etc., all exist in my present reality at June 2, 1996, 3 pm, hence tomorrow. If we put it like that, we are confronted even more with a counterintuitive aspect of the Einsteinian interpretation of relativity theory. But it is a correct statement in our framework. We have to add, however, that all these objects that are very close to me now, June 1, 1996, 3 pm, indeed also exist in my present reality at June 2, 1996, 3 pm, but the place in reality where I could have observed them is of course much further away from me. Indeed, to be able to get there, I have to fly away with a space ship at nearly the velocity of light. We now come to a very peculiar question that will confront us with the singularity of our reality construction. Where do I myself exist? Do I also exist tomorrow June 2, 1996, 3 pm? If the answer to this question is affirmative, we would be confronted with a very paradoxical situation. Because indeed, I myself, and this counts for all of us, cannot imagine me to exist at different places of

time. But indeed our framework clarifies this question very easily. It is impossible for me to make some action in my past such that I would be able to observe myself tomorrow June 2, 1996, 3 pm. Indeed, if I had chosen to fly away and come back with the space ship such that I observe now, June 1, 1996, 3 pm, on my personal watch, the inside of my house tomorrow June 2, 1996, 3 pm, then I could do this, and, as remarked already, it proves that this inside of my house tomorrow is part of my present personal reality. But I will not find myself in it. Because to be able to observe my house tomorrow, June 2, 1996, 3 pm, I would have to move out of it. Hence, in this situation I will enter my house, for myself being still at June 1, 1996, 3 pm, but my house and all things in it, being at June 2, 1996, 3 pm. This shows that there is no paradox.

3.5. The Construction of Reality and Quantum Physics

To be able to use this framework for an attempt at a unification between quantum mechanics and relativity theory, much work still has to be done. But what we have achieved is that we see clearly “what reality is” as confronted with both theories. For a more detailed analysis of quantum mechanics in our framework see Aerts (1992). In a subsequent article I will apply this framework and the analyses made here for relativity theory and the one in Aerts (1992) for quantum mechanics to put forward a theory about physical reality and the way this reality changes.

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