An Outside View of Space and Time

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Abstract

According to the standard interpretation of the special theory of relativity, space and time form a unity, which is described by the so-called Minkowski geometry. Using a distinction between inside and outside views, an alternative interpretation of special relativity can be formulated. This interpretation is connected to the construction of an outside view of space-time, which is described by a 4-dimensional and fully Euclidean geometry. The construction of an outside view also for general relativity is attempted, the basis for which lies in the assumption that the speed of light in a gravitational field – as seen from the outside - depends on gravitational potential and on direction. Finally, it is argued that the suggested outside view might serve as a basis for new approaches in the philosophy of space and time.

Keywords: space, time, relativity, inside versus outside view

1 Introduction

What is the contribution of relativity theory to our understanding of space and time? The answer to this question depends on the chosen interpretation of relativity theory. In addition to the standard interpretation, which is connected to the Minkowski space-time geometry, there are also less known Lorentz-type interpretations (Lorentz, 1909; Ehrlichson, 1973), which are based on the separate treatment of space and time. In this paper, an alternative will be formulated that significantly differs from both interpretations.

As a conceptual tool, an elementary distinction between inside and outside views is introduced in section 2. Both established interpretations will be criticized for an unclear status concerning this inside-outside distinction.

In section 3, the special theory of relativity (Einstein, 1905) is introduced from the perspective of an outside observer holding a fully Euclidean geometry. The relevant statements will be illustrated by the use of light clocks in one space dimension.

In section 4, a first step toward the construction of an outside view of general relativity (Einstein, 1916) is made. The outside geometry for general relativity is exactly the same, namely 4-dimensional and fully Euclidean. The difference to special relativity is explained by the assumption that the speed of light – as seen from the outside – depends on gravitational potential and direction. Again, light clocks in one space dimension are sufficient to illustrate the relevant statements. Most importantly, it is

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illustrated how the trajectory of a free falling light clock follows from the chosen assumptions.

In section 5, the alternative interpretation is compared to the standard and to Lorentz-type interpretations. It is argued that the suggested outside view might serve as a basis for new approaches in the philosophy of space and time.

2 Inside Versus Outside Observation

In the final analysis, every observation – scientific or not - is an *inside* operation in the sense that it is performed by an observer who himself is part of the universe and who interacts with what he observes via a physical operation. Therefore, the result of every measurement has to be regarded as a product of both observer and observed and cannot be taken to capture a property of the observed thing as such. Thus, our view of the world in the first place is an *inside view*. In order to construct an *outside view*, an act of abstraction is necessary. What is abstracted away in the outside picture is the observer and the act of observation. When saying that a piece of wood has the property to be one meter in length, we have already abstracted from the physical operation called length measurement, which consists in a comparison of this piece of wood to a meter stick. To some extent, the scientific method can be understood as a set of strategies that allow to abstract from the observer and the act of observation. One of these strategies is the strict normalization of measuring instruments that are used by different observers.

The abstraction from the process of observation leads to the construction of an outside view. The hypothetical outside observer holds a god-like position and sees things "as they are". In this paper, a radical outside view of relativity theory is suggested, from whose perspective the views of all inside observers can be explained. It will be argued in section 5 that both the standard interpretation and Lorentz-type interpretations of relativity are not successful in their attempts to construct outside views.

3 An Outside View for Special Relativity

The outside view that is suggested as the basis for an alternative interpretation of special relativity is a 4-dimensional and fully Euclidean geometry. The views of all inside observers can be derived from this outside geometry. As the simplest approach to inside observation (from an outside view), the concept of a light clock will be introduced. By its use the most relevant statements of special relativity can be illustrated.

3.1 The Statements of Special Relativity

As a basis for the following alternative introduction to special relativity, some important definitions and statements of special relativity are listed. Some of them play different roles depending on the chosen interpretation.

3.1.1 Definition of Synchrony

Einstein defines two events as synchronous, if light beams that are caused by these events meet in the spatial middle. For defenders of a Lorentzian position, Einstein's concept of synchrony is a mere convention; apart from that, absolute synchrony is supposed to exist.

3.1.2 Definition of Length Measurement

According to Einstein's definition, the measurement of a spatial distance has to take place simultaneously from the view of the measuring observer.

3.1.3 Constancy of the Speed of Light

In Einstein's development of the calculus, the constancy of the speed of light is assumed for every inertial observer, independent of the speed of the source of a light beam. For Lorentz-type interpretations, the speed of light is *really* constant only for the *true* rest frame; light is measured constant also by all other inertial observers due to length contraction and time dilation of the measuring instruments.

3.1.4 Relativity Principle

The relativity principle stating that the physical laws are independent of the frame of reference appears as an assumption in the standard derivation. For Lorentz-type interpretations, the validity of the relativity principle follows from length contraction and time dilation.

3.1.5 Length Contraction and Time Dilation

In the standard approach, length contraction and time dilation are derived mainly from the constancy of the speed of light and the relativity principle. For Lorentz-type interpretations they have to be taken as assumptions.

3.2 Light Clocks and Space-Time Units

Einstein's definition of synchrony, the assumption of the constancy of the speed of light and the definition of the measurement procedures very easily lead to the concept of a *space-time unit* as the basis of an *inside* observer's geometry.

When looking at fig. 1 we are in the position of an outside observer, whose space-time geometry is Euclidean. Therefore, graphical illustrations and calculations are very simple and easy-to-comprehend. The scaling of the time axis with the constant velocity c makes light beams appear as 45° lines. Both inside observers S and S' are represented by a pair of world lines between which two light rays are reflected. Each inside observer synchronizes these light beams such that they meet in the world line of the middle point M of the light clock. By this, the definition of synchrony is fulfilled for events A and B (resp. A' and B') as well as for C and D (resp. C' and D').

For S, the space-time distances between A and B and between C and D are lengths and the distances between A and C and between B and D are time intervals. The same is valid for S' and the events A', B', C' and D'. Let us call the quadrangle made up of these events the *space-time unit* of the corresponding inside observer. From the outside view the space-time unit of the resting observer S is a square, whereas the space-time unit of the moving observer *S'* is a parallelogram that shows an angle γ not only for its time axis, but also for its space axis. This does not imply that it would be possible to determine the ("really rectangular") outside view from the inside, which would result in a violation of the relativity principle. Every linearly moving inside observer can consider himself as an outside observer, i.e. draw rectangular diagrams – this follows from the way the space-time units are defined in the Euclidean geometry. In terms of Lorentz-type interpretations, this assertion relates to the statement that any inertial observer could be the one resting in the ether (Bell, 1994).

Note that the constancy of the speed of light holds for all inside observer who define their light clock to be one meter long and who define the time interval between two ticks as one second divided by *c* (speed of light).

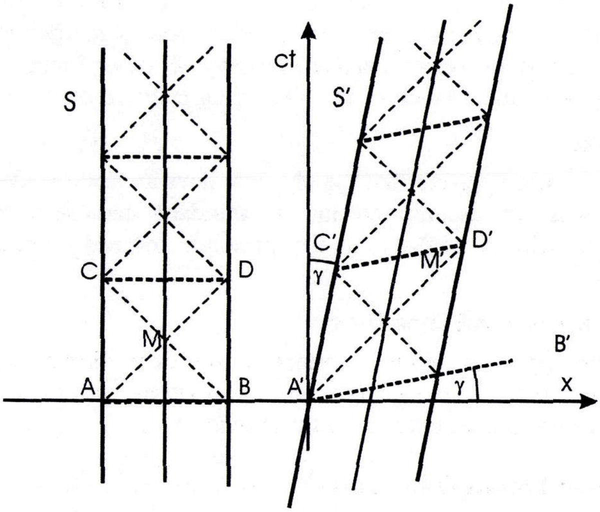

Fig. 1: The space-time units of two observers *S* and *S'* from the point of view of an outside observer.

3.3 Measuring Lengths

The measurement of lengths (and time intervals) is determined by the definition of an inside observer's space-time unit. Fig. 2 shows two observers in relative motion who take their own length to be *one meter*. The simultaneous measurement of the other observer's extension marks a space-time distance that is compared to the meter stick of the observer performing the measurement. For *S'* the length of *S* is x_1 divided by *one meter(S')*. For *S* the length of *S'* is x_2 divided by *one meter(S)*.

From the outside view every measurement is a comparison between space-time extensions defined in a Euclidean geometry. A possible identity of the results of two measurements (such as in fig. 2) only says that the relations between object and meter stick are identical; it is not justified to conclude that both measured objects are equal or that both meter sticks are equal. The two light clocks in fig. 2 are in fact not equal from the outside view; they are not equal from the view of any inside observer, as well. Accordingly, it is a legitimate question in which sense the two light clocks represent the *same* scales of space and time, as is assumed in the standard interpretation. Note that this *normalization problem* needs to be solved for a the construction of a useful outside view; for a discussion of the normalization problem in special relativity, see (Winkler, 2001).

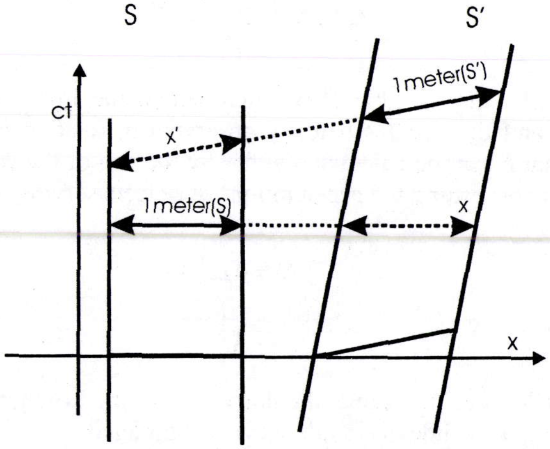

Fig. 2: Two observers measure each other's lengths. From the outside view every measurement is a comparison between Euclidean space-time distances.

3.4 Derivation of the Transformations of Space and Time Distances

The following analysis makes use of the fact that space and time measurements performed by inside observers are comparisons of space-time extensions in a Euclidean geometry when seen from an outside view.

The transformations of space and time distances held by an inside frame *S* to another inside frame *S'* moving with velocity *v* can be derived by the use of fig. 3. The two frames in fig. 3 have a common origin in event *O*. In both frames the space and time coordinates of event *P* are measured. From the (outside) perspective of the diagram frame *S* is at rest, while frame *S'* is in motion along the x-axis. However, the following argument holds for any pair of inside observer. As has already been shown in fig. 1, in such illustrations the space and time axes of frame *S'* have the same angle relative to the axis of the resting frame *S*. From this it follows that the triangles *ABP* and *CDP* are similar, which allows to formulate the following relation:

$$N = \frac{x'}{x - v \cdot t} = \frac{c \cdot t'}{c \cdot t - \frac{v \cdot x}{c}} \tag{3.1}$$

As a consequence of (3.1), the transformations of space and time distances from frame *S* to frame *S'* take the form:

$$\begin{aligned} &T(S \Rightarrow S') \\ &\Delta x' = N \cdot (\Delta x - v \cdot \Delta t) \\ &\Delta t' = N \cdot \left(\Delta t - \frac{v \cdot \Delta x}{c^2}\right) \end{aligned} \qquad (3.2)$$

In (Winkler, 2001), the variable *N* is discussed in the light of the normalization problem for space and time scales held by observers in relative motion. In the same place it is shown that *N* can be calculated either by the use of the relativity principle or from an assumption concerning the acceleration[1] of objects serving as meter sticks.

$$N = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad (3.3)$$

By showing that *N* takes this value, the derivation of the Lorentz transformations for inside observers from a Euclidean outside view is completed.

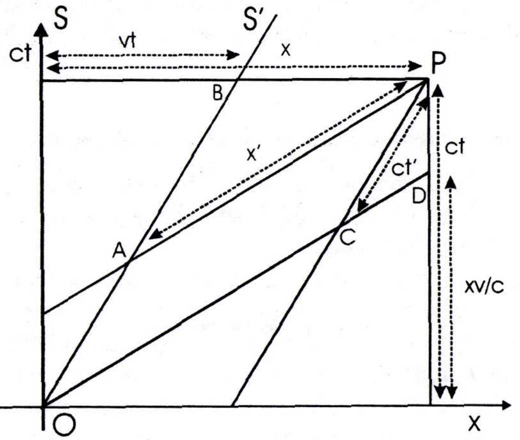

Fig. 3: The coordinates of event *P* are measured in the resting frame *S* and in the frame *S'* which moves relative to *S* with velocity *v*. Both coordinate systems are assumed to have the same origin *O*. The similarity of the triangles *ABP* and *CDP* allows to formulate the transformations of space and time distances from frame *S* to frame *S'*.

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[1] By this, an assumption on acceleration becomes part of the basis of special relativity, which deeply contradicts the spirit of the standard interpretation. However, solving the normalization problem by the relativity principle makes the Lorentz transformations a matter of mere convention (Winkler, 2001).

4 Toward an Outside View for General Relativity

It is, of course, not sufficient to show that an outside view of special relativity can be constructed. The suggested interpretation of relativity theory demands that also general relativity can be understood from the outside. In this place, it is only possible to make an intuitive first step. For this purpose the already introduced concept of a light clock suffices. By its use, the time dilation of clocks in a gravitational field will be illustrated. It will also be shown how the trajectory of a free falling object (a light clock) looks like from an outside view.

The following three assumptions lay the basis for the suggested approach to general relativity.

(1) Special relativity is the limiting case of general relativity.

(2) Free fall is inertial motion.

(3) From an outside view, the speed of light in a gravitational field depends on the distance to a gravitational object (i.e. on gravitational potential) and on direction. Incoming light is faster, while outgoing light is slower.

The assumptions (1) and (2) are adopted from standard general relativity, assumption (3) makes sense only for a hypothetical outside observer who is not affected by gravitation. Therefore, it only seems to be in contradiction to standard general relativity; as a mere outside observer's statement assumption (3) cannot be judged by inside measurements. For inside observers, the speed of light in a gravitational field is always (at least locally) measured to the same value in all directions.

4.1 Outside Rotation and Inside View

A very simple and intuitive example illustrating the possibility of different light speeds in different directions according to assumption (3) is given by an outside space-time rotation in a Euclidean geometry.

Fig. 4 shows two scenarios involving the space-time units of inertial observers in relative motion. The second scenario is rotated from an outside view, which implies that the speed of light differs from c and depends on direction. However, this difference is visible only from the outside; from the inside, the speed of light is constant for all observers and there is no difference between the two scenarios. Therefore, special relativity is valid also in the rotated case.

The idea behind the presented approach to general relativity is to understand the phenomena of gravitation mainly as consequences of Euclidean space-time rotations. Depending on the vicinity to a gravitational object (i.e. depending on gravitational potential), the trajectories of light are more or less rotated from an outside view. It should be noted that this assumption, after a generalization to a second or third spatial dimension, directly explains the bending of light near gravitational objects. Also the slowing down of clocks in gravitational fields becomes intuitively clear.

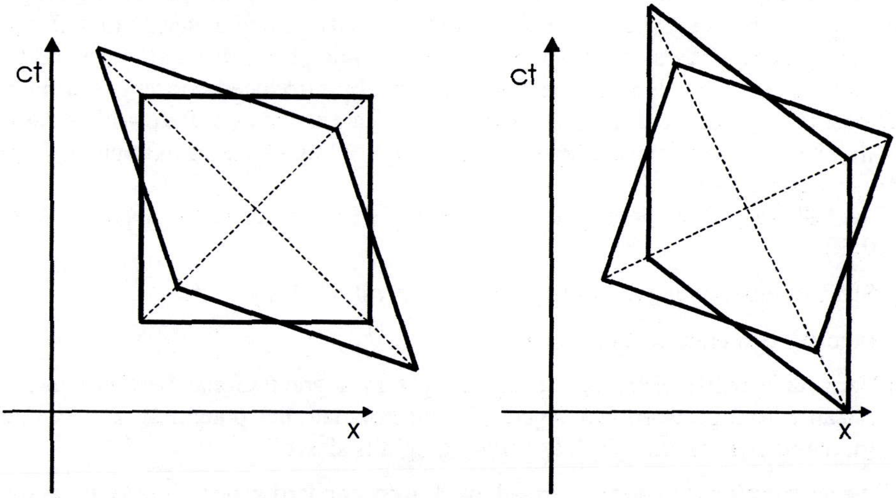

Fig. 4: An outside rotation of the space-time units belonging to inertial observers in relative motion. From the outside, the speed of light in the rotated scenario differs from *c* and depends on direction. From the inside, i.e. for the involved inertial observer, there is no difference between the rotated and the non-rotated scenario.

4.2 Light Clocks in a Gravitational Field

Fig. 5 shows four light clocks resting in a gravitational field whose center lies somewhere on the right side of the diagram. The differences in the speed of light according to assumption (3) result in space-time units that are not only "stretched" as is the case for moving clocks in special relativity (see fig. 1), but also rotated according to fig. 4. Note that the continuous changes of the light velocities are simplified to discrete changes in order to show the connection to special relativity. In the infinitesimal limit, the light clocks can locally be treated in the same way as in special relativity, which has been addressed in assumption (1). Comparing the time intervals of the resting light clocks makes clear that time is slower for observers located close to the center of gravity than for observers far away from the center of gravity. By this, gravitational redshift is explained. It also can be read from the diagram that the simultaneity relation between events looses transitivity. Although *A*, *B*, *C*, *D*, and *E* form a chain of locally simultaneous events, the events *A* and *E* are not simultaneous; the meeting of light beams started in *A* and *E* takes place at event *X* which is not located in the middle.

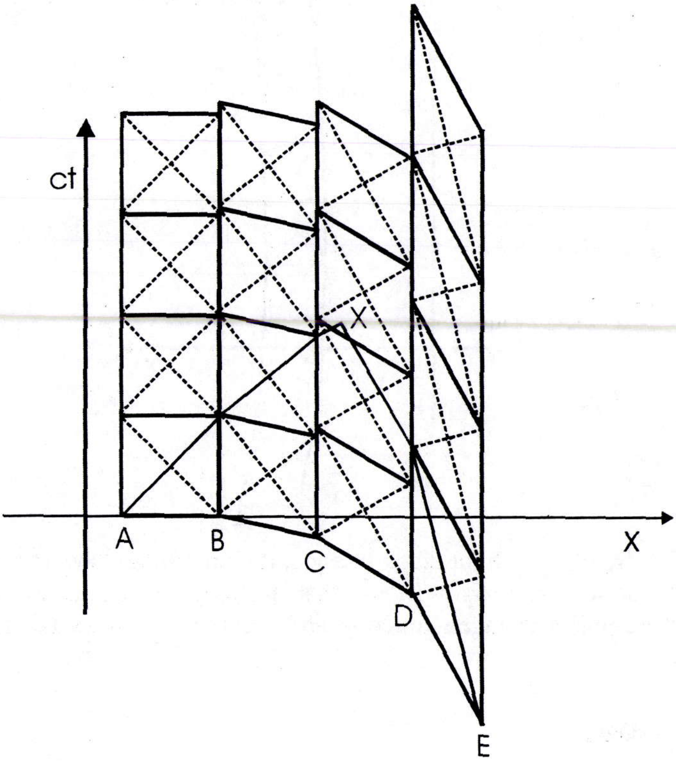

Fig. 5: Resting light clocks in a gravitational field from an outside view. The speed of light depends on the distance to the center of gravity (somewhere on the right side) and on direction: outgoing light beams are slower, incoming light beams are faster than light beams far away from the gravitating object. Light clocks that are closer to the gravitating object go slower. The events *A* and *E* are not simultaneous, as the meeting point *X* of light beams started at *A* and *E* is not located in the middle.

4.3 Free Fall

Fig. 6 shows a light clock free falling in a gravitational field. The trajectory of the light clock is a consequence of assumption (2) stating that free fall is inertial motion. From this it follows that the clock has to move such that the reflected light beams always meet in its middle. The differences in the light speeds depending on location force the light clock, which at the beginning moves away from the center of gravity, to change direction and to finally move toward the center of gravity.

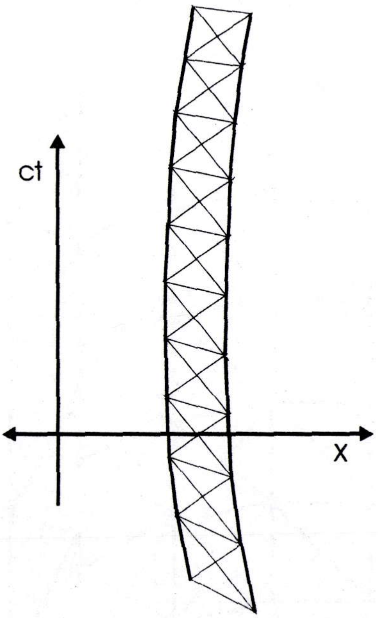

Fig. 6: A free falling light clock in a gravitational field. Obeying the law of inertial motion, the light clock that initially moves away from the gravitating object changes direction and accelerates toward the gravitating object.

4.4 Open Questions

The suggested outside view of general relativity is far from being fully developed. The viability of the outside view must be checked by a mathematical model, which does not yet exist. In the following, some important questions for a further development of the approach are addressed.

The assumption that the trajectories of light beams in a gravitational field appear as perfectly rotated from an outside view might turn out as an idealization. However, the inclusion of different kinds of geometrical transformations would not violate the general picture; especially the validity of special relativity in the local limit (assumption (1)) would remain untouched.

A related point concerns the question how the trajectories of light beams going through a gravitational object would look like; the problem consists in drawing a spatially symmetric picture that does not contain unrealistic discontinuities. A naive extrapolation of fig. 5 would either lead to a black hole scenario or would require instantaneous jumps of the speed of light in the middle of the gravitating object.

The proposed outside view of general relativity is clearly not time symmetric; depending on the answers to the previous questions a temporal asymmetry might arise also for inside observers.

Finally, it should be pointed out that the construction of a consistent outside view of general relativity on the basis of the presented considerations would not necessarily imply full equivalence to standard general relativity; e.g. in the question whether there exist black holes or not.

5 Different Outside Views of Space and Time

From the suggested Euclidean view of space-time, the standard interpretation of relativity theory as well as Lorentz-type interpretations do not provide full outside views in the sense of section 2.

The standard interpretation offers the so-called Minkowski space-time geometry as an outside view[2]. Meter sticks and clocks resting in different frames are treated ontologically equivalent, which is not acceptable for a real outside view. When two frames in relative motion cannot be distinguished by the use of inside measurements, outside equivalence is not at all a logical consequence. However, this seems to be the conclusion standing behind the standard interpretation. Rather than accepting the (outside) difference of measuring instruments and measuring procedures of frames in relative motion, length contraction and time dilation are understood as products of a relation (i.e. the relative motion) between measuring instruments that are assumed to be equal. The problem behind this view is addressed as the normalization problem in (Winkler, 2001), where the standard interpretation of relativity theory is shown to require a *conventional* solution to the normalization problem. The equality of scales used by different observers by mere convention, however, can in no way justify ontological equality which is the basis of the standard interpretation.

Lorentz-type interpretations seem to be quite aware of the inside-outside problem; a clear conceptual distinction is made between *ontological* and *epistemological* equivalence. What is missing for a real outside view, though, is the integration of the time axis into the outside picture[3]. In the Lorentz view, the time axis is independent of the spatial geometry; it is assumed that absolute simultaneity exists and that time flows objectively, which would imply that it also flows for an outside observer. For the suggested interpretation, the concept of outside observation standing behind this view is not satisfying, because all past and future states of the world would not be included in such an outside view[4]. A real outside view should comprise space *and* time and should have the potential to explain the perceived phenomena of time as inside phenomena. This postulate is a natural consequence of the suggested outside view.

Although this is not the place to develop a theory of time, some remarks on a possible basis for this enterprise can be made. First of all, it has to be stressed that for

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[2] A prominent example of an outside view of space-time in the sense of general relativity can be found in (Hawking, 1988).

[3] The need for an outside view of time is argued in (Price, 1996); the integration of space and time according to relativity theory, however, is not addressed.

[4] The limitations imposed by the separate treatment of space and time might be the cause of the obvious problems of creating a Lorentz-type model of general relativity. The suggested space-time rotations of light trajectories would hardly be acceptable in a Lorentz-type approach.

the Euclidean outside geometry there does not exist a difference between space and time dimensions; in other words, the dimension which is experienced as time by inside observers is nothing but another space dimension for the outside observer. But how can the experienced difference between space and time be explained from the outside view? An answer to this question becomes possible, once the universe is understood as a 4-dimensional "object" with certain structural properties.

As an illustration of this, consider the following example: If the trunk of a tree is described in 3-dimensional space, an observer can recognize structural differences in different directions, e.g. the fibrous structure of the wood. However, nobody would say that this structure, which might be oriented along the observer's z-axis, is a property of the z-axis. If the tree is cut down, or if the observer looks from a different angle, the wood's structure would no longer be a z-structure (for an "inside" woodworm the situation would, of course, be different). In a similar way the obvious differences between space and time are not due to a special role of one of the outside observer's dimensions, but have to be regarded as properties of the 4-dimensional "object" called universe. For a theory of time, the starting point must be to understand objects as well as inside observers themselves as sub-structures of the 4-dimensional whole. What appears as a temporal relation for an inside observer has to be understood as a space-time relation with some specific geometrical properties, just as space-time relations with some other properties would be interpreted as spatial relations by the inside observer.

In (Winkler, 1999), where a conceptual basis for the analysis of space-time structures has been laid, this approach is applied to the spatial relations between a perceived object and its representation in a cognitive system.

6 Concluding Remarks

In the inter-disciplinary discussion of the nature of space and time, physics takes a dominant role. Any approach that stands in contradiction to accepted physical theory is simply doomed to fail. What has been attempted in this paper is to show that the standard interpretation of the theory of relativity can and must be criticized for an unclear treatment of elementary philosophical questions. The suggested alternative view of relativity starts from a distinction between inside and outside views, which addresses a problem that is so fundamental to the scientific method that it is easily overlooked. The completely Euclidean outside geometry, whose viability is shown for special relativity, and which is suggested also for general relativity, is simple enough to be understood by non-physicists. Therefore, it might serve as a basis for new inter-disciplinary approaches to space and time.

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