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Principle of Causality and Inertial Frames of Reference

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Abstract

A hypothesis is proposed that generalizes the principle of causality. The hypothesis assumes that the principle of causality is applied separately and independently for each different inertial reference frame. It was noted that the observer has only the information that the inertial reference frame relative to which he is stationary has. Further analysis led to the conclusion that from the observer's point of view, any event exists in all inertial reference frames, even if it exists only in a part of the inertial reference frames. The hypothesis leads to the fact that two types of transformations arise during the transition between inertial reference frames. The first is the transformation from the observer's point of view. The second type of transformation is direct transformations of space-time and fields. When considering the hypothesis, it was noted that all modern widely accepted theories rely on the principle of causality. At the same time, the principle of causality does not depend on them, it is more fundamental. Therefore, the hypothesis can be considered based only on the principle of causality, without taking into account any other principles and physical theories. If the hypothesis is true, then all modern physical theories satisfy only the first type of transformations. The hypothesis allows for a new class of theories to be created that take into account the second type of transformations. These theories can lead to new predictions. Therefore, it can be argued that the hypothesis is, in principle, falsifiable. If the hypothesis is true, then there is something more fundamental than space-time.

Keywords

Principle of Causality, Inertial Frames of Reference, Spacetime

1. Introduction

The principle of causality is one of the most general physical principles. As a study of the literature shows that there have been no attempts to generalize this principle.

Let us look for opportunities for such a generalization. We consider the formulation of the principle of causality to be correct, and we do not try to modify it. Then all that remains is to search for some implicit postulate of the principle of causality, which is accepted a priori, without experimental confirmation. After that, it will be necessary to find a possibility of its modification. In this case, since the formulation of the principle of causality does not change, the new generalized principle must transition into the existing one as the difference between the implicit postulate of the principle of causality and its modification tends to zero.

Obviously, this can only be some very fundamental postulate, which is perceived as obvious without evidence and without experimental verification, and which has never been questioned before.

We consider only inertial reference frames (IFR). For space-time with curvature, we consider local inertial reference frames.

2. The Place of the Principle of Causality in Modern Physics

We are looking for a possibility to find some implicit postulate on which the principle of causality relies on, and which can be separated from the principle of causality. The modification of the principle of causality in this approach consists in separating this implicit postulate from the principle of causality, and in the subsequent modification of this postulate. At the same time, we do not change the formulation of the principle of causality.

Let us assume that we find this implicit postulate and find possibilities for its modification. In modern physics, there are a number of widely accepted and well-tested theories. The question arises as to what needs to be considered for the described modification of the causality principle. Should we take into account existing physical theories and other physical principles, or is the causality principle completely independent of everything else? In order to consider the causality principle independently of other physical principles and existing physical theories, it is necessary that these theories and principles depend on the causality principle, but not vice versa.

The most fundamental and widely accepted theories in modern physics are the general and special theories of relativity, and quantum physics. Among other physical principles, the principle of locality can be distinguished.

Let us consider the special theory of relativity (STR). We will show that it depends on the principle of causality.

The first postulate of STR mentions the laws of nature. The laws of nature connect the initial state, which can be considered as a cause, and the state at some subsequent moment in time, which can be considered as effects. The second postulate of STR mentions the movement of light in a vacuum. That is, there is something that moves under certain conditions at some point in time, and it is stated that it will behave in such and such a way. Here, too, cause and effect are visible. There are no visible ways to formulate the postulates of STR without relying on the principle of causality. From this it clearly follows that STR relies on the principle of causality.

Since STR depends on the principle of causality, any consequences of STR depend on the principle of causality. We note separately that Minkowski space is a consequence of STR and, therefore, also depends on the principle of causality.

General Relativity (GR) depends on STR. Therefore, it can be argued that GR depends on the principle of causality.

The principle of locality states that an object is influenced only by its immediate surroundings. Here, too, there are causes and effects. Something is near the object, and it influences the behavior of the object at subsequent moments in time. Therefore, the principle of locality depends on the principle of causality.

There are no known physical principles on which the principle of causality is based.

We have obtained that when considering the above-described problem of separating some implicit postulate from the principle of causality, we can consider only the principle of causality. That is, it is not necessary to take into account any other physical theories and physical principles. So, we consider the principle of causality without relying on any other physical principles and physical theories.

3. Principle of Causality

Let's consider the principle of causality. The principle of causality says that any event is caused by something, and has a reason. In classical physics, based on the previous state of the system, it is possible to uniquely find the state of the system at any subsequent moment in time. In quantum physics, the state of the system is usually described through wave functions, and it is only possible to find the probability of finding the system in a certain state when measured. The principle of causality allows, knowing the state of the system at some point in time, to find the state of the system, or the probability of finding the system in some state when measured, at any subsequent moment in time. This can be written as follows:

$$\varphi(t+dt) = A\varphi(t) \tag{1}$$

Here φ is the state of the system or its wave function when using the quantum description, t is time, A is some operator. The state of the system φ includes the set of values that is necessary to describe the system. For example, to describe a system of bodies based on Newton's law of universal gravitation, if we consider bodies as material points, masses, velocities and coordinates of bodies are sufficient to describe the state. Accordingly, the value must consist of the mass, velocity vector and coordinates of the body.

According to the principle of causality, there are no events without a cause. Someone might think that, for example, the radioactive decay of an atomic nucleus has no cause. Let's look at Equation (1). The radioactive decay of a nucleus is obviously described by this Equation. Therefore, it also corresponds to the principle of causality. The principle of causality does not mean determinism. There are many discussions of this issue. Note that if there were at least one phenomenon that violated the principle of causality, this would mean a refutation of this principle.

Equation (1) describes causality both when using the description of classical physics and when using quantum physics. It is clear that having a wave function, we can obtain the probability of finding the system in some state during measurement. We want to describe the transformations for both the classical case and the quantum case, therefore, further, for brevity, when we talk about the transformations of the state during the transition between the IFR and the system is quantum, we talk about the transformation of the wave function.

Some events cannot influence other events because they are separated by a space-like interval. There are other constraints for other formulations, for example, Bogolyubov's micro-causality condition [1]. Such constraints can be considered as additional constraints on the operator A. For the purposes of this hypothesis, both these constraints and any detailed properties of the operator A are unimportant and will not be considered. As discussed above, we consider the principle of causality without relying on any physical theories or other physical principles. The only important thing is that there is some operator A, with some properties, which transfers the system from the state at time t to the state at time $t+dt$.

It may be noted that Equation (1) alone is not sufficient for the principle of causality. Suppose we know the state of a system in some inertial reference frame. Let us designate this IFR as K. Is it possible to find the state of the system in another IFR, K', moving with a non-zero velocity relative to K on this basis? If this is impossible, then events in different inertial reference frames cannot be related to each other. However, the practice of applying the principle of causality in modern physical theories implies that, knowing the state of a system in one inertial reference frame, we can obtain the state of the system in another inertial reference frame. Thus, for the principle of causality to be satisfied, the following equation must also be satisfied, for each φ_i' and t_i', for an arbitrary K':

$$\begin{gathered}\varphi_i'(K') = B_{\varphi i}\varphi(K) \\ t_i'(K') = B_t t_i(K)\end{gathered} \tag{2}$$

Here φ_i' is one of the set of states in K', t_i is the time in K for φ_i, the *i*-th element of the set φ, t_i' is the corresponding time in K', $B_{\varphi i}$ is some operator that transfers the state of the system from K to K' for φ_i, B_t is the operator that transfers the time from K to K'. We will not consider the properties of these operators here.

The transformation above is usually written slightly differently. To find a state at some point in space-time in one IFR, one usually takes a state in another IFR at some point in space-time, relying on the principle of locality. Equation (2) includes such a description as a special case, when φ_i' depends not on all states in K, but only on the state at some point. Since we consider only the principle of causality, without relying on any other principles and physical theories, we have no reason to write the equation this way.

If two IFRs have zero relative velocity, and differ in the origin of coordinates or orientation of the axes, then a simple transformation can convert one IFR to another. In order to exclude such transformations from consideration, we will further consider only different IFRs. For our purposes, we will define two IFRs as different if they have non-zero relative velocity.

Now let's look at Equation (1) again. We want to separate the transformation of state during the transition between IFRs from the change of state over time. Let's change the equation to the following:

$$\varphi(t+dt,K)=A\varphi(t,K) \tag{3}$$

Now $\varphi(t,K)$ denotes the state of the system not just at time t, but also in some IFR K. The operator A, accordingly, translates the state of the system between different moments of time in the same IFR.

Then, to fulfill the principle of causality, it is necessary to simultaneously fulfill two Equations, (2) and (3), which leads to a system of equations:

$$\begin{gathered}\varphi(t+dt,K)=A\varphi(t,K) \quad (4)\\ \varphi_i'(K')=B_{\varphi i}\varphi(K)\\ t_i'(K')=B_t t_i(K)\end{gathered}$$

Equation (1) allows us to describe the causality principle when we do not consider in detail the properties of transformations between IFRs. Equation (4) is needed for a more detailed analysis of how the causality principle and transformations between IFRs are related.

4. Principle of Causality and Inertial Reference Systems

Let us consider space-time, with some fields, containing an observer. The observer can be either some device or a rational being. We assume that the principle of causality is fulfilled in this space-time.

Further, an event will mean an event that is described by the principle of causality.

Consider the following question: can the space-time in question contain causal relationships that begin with an event that did not occur in this space-time?

An example of an event can be a collision of two bodies. It does not matter whether these are elementary particles described by quantum physics or some large bodies. What is important is that, according to established views in physics, if an event, a collision of two bodies, for example, occurred in one IFR, then it occurs in all IFRs. This means that Equation (2), the transformation of state between IFRs, must preserve events. An event, after the transformation, may change some properties, the spatio-temporal distances with other events may change, but the event itself occurs in all IFRs.

Causal relations starting from an event that did not occur in this space-time can be described as a set of states at some time t in some IFR that do not follow from the set of states at time t_0. That is, the set of states $\varphi'(t)$ contains states that are not included in the set $\varphi(t)$, where $\varphi(t)$ satisfies Equation (3) and follows from the state at time t_0. Obviously, this contradicts Equation (3), and is therefore impossible. The expected result, because otherwise it would violate the principle of causality.

Let us consider the question of how information about an event can be described from the point of view of the principle of causality. Some event occurs, after which there are cause-and-effect relationships starting from this event. Then information about an event is a set of cause-and-effect relationships starting from this event.

Suppose that Equation (2) does not preserve events across inertial reference frames or is not satisfied at all, and Equation (3) is satisfied. Then, an event may exist in some set of inertial reference frames and not exist in another set of inertial reference frames. This assumption means that the causality principle applies separately and independently to each different inertial reference frame. This is the basic assumption of the hypothesis.

For the case of wave function transformation, non-preservation of events during the transition between IFRs means a change in the probability of the system being in some state, including the emergence of new possible states after the transition and the disappearance of some states that existed in the previous IFR before the transition.

Let us note right away that in any space-time, the transition between IFRs is simply a change in the coordinate system. If some event occurred in space-time in some IFR, then if we simply change the coordinate systems, this event will be in all IFRs. Therefore, the main assumption of the hypothesis means that space-time is not fundamental, and the transition between IFRs is not a simple change in the coordinate system.

Let us define what is the application of the causality principle independently and separately for each different IFR. We consider that the causality principle is applied separately and independently for each different IFR if Equation (3) is satisfied, and Equation (2) does not preserve events during transition between IFRs. Note that a special case of non-preservation of events when moving between IFRs is the case when Equation (2) is not satisfied at all, *i.e.*, based on the state of the system in one IFR, it is impossible to determine the state of the system in another IFR.

If the causality principle is applied independently for each IFR, then there may be differences in the cause-and-effect relationships in different IFRs. Differences in the cause-and-effect relationships mean that some events may have occurred in one IFR and not occurred in some other IFR. The difference in events also means differences in objects. As an example, as a result of the event of a collision of two electrons in one IFR, several new particles were generated, while in another IFR this collision did not occur, so new particles could not have appeared. We do not assume that the difference in events is limited to the micro level. With a sufficiently large difference in events, the Moon may exist in one IFR and not exist in another IFR.

We would like to note separately that the situation when some events occur simultaneously in one IFR and, according to the theory of relativity, at different times in other IFRs, does not lead to differences in cause-and-effect relationships.

If there are differences in cause-and-effect relationships in different IFRs, this leads to the fundamental impossibility of transferring information between IFRs about events that are not in another IFR. To transfer such information, it is necessary that an event that is not in the IFR has an effect on events that are in the IFR, which contradicts the principle of causality if applied independently to different IFRs.

Now let us consider how the independent application of the principle of causality affects the observer and the information available to the observer.

5. Principle of Causality and the Observer

In what frame of reference does the observer observe? The answer to this question is quite obvious. The observer observes in the frame of reference relative to which he is stationary. If this were not so, then, for example, receiving a signal from a satellite about his observations, it would be impossible to say that the signal from the satellite carries information about what is happening in the frame of reference relative to which the satellite is stationary.

From this, the conclusion immediately follows: The observer cannot have information about an event that did not occur in his IFR, the IFR relative to which he is stationary.

This is an important observation that we will use further. Note that this observation does not depend on this hypothesis.

Let us denote the set of events and cause-effect relationships in the IFR K at time t as $Ev(K,t)$. After moving to another IFR K' the observer's time changes to t'. K' has its own set of events and cause-effect relationships, $Ev(K',t')$. If the events are preserved during the transition between IFRs, then these two sets coincide for any IFRs. If the causality principle is applied separately and independently for different IFRs, then these sets may differ. Let the observer be stationary relative to the IFR K. The observer can observe events only in the IFR relative to which he is stationary. Therefore, only the set $Ev(K,t)$ is available for observation to him. He cannot in any way observe events belonging to the set $Ev(K',t')$ for any K' different from K.

You can try to build different schemes on how to get information from more than one IFR, but they all run into one insurmountable problem. The problem is that to get information from some other IFR, you need to eliminate the transition transformation between IFRs, Equation (2), which is impossible.

Suppose that Equation (2) does not preserve events when moving between IFRs or is not satisfied at all, Equation (3) is satisfied. Then, an event may exist in some set of IFRs and not exist in another set of IFRs. Let us consider how an observer will perceive this, whether the events will differ between IFRs from the observer's point of view. For our purposes, we assume that if some event exists in all considered IFRs, then this event does not differ between IFRs, even if some properties of the event change.

An observer can obtain information about what is happening in other IFRs in two ways. The first way is to receive a signal with information from an observer who is at rest relative to another IFR moving with a non-zero velocity relative to the first observer. The second way is that the observer can change his velocity and move to another IFR. Let us consider, for each of the options, how the events will look from the observer's point of view.

Let us consider the first method. Let there be an IFR K and an IFR K' moving with non-zero velocity relative to each other. In K, let there be an observer 1, motionless relative to it. In K', there is an observer 2, motionless relative to this IFR. Observers 1 and 2 exchange information about what they observe. Let the signal sent by each observer contain information about an event that is in the IFR of the observer who sends the signal, but is not in the IFR of the receiving observer. Can the receiving observer receive information about an event that is not in his IFR? This information can be described as a certain set of cause-and-effect relationships starting from an event that was not in this IFR. Or, in other words, as a set of system states that do not satisfy Equation (3). As was discussed above, this is impossible. Therefore, no matter what the other observer sends, for the receiving observer, the signal received cannot contradict the principle of causality and Equation (3).

Now consider the second way. An observer observed something, saved the results of his observations on numerous instruments. After which, the observer changes his speed and begins to have zero speed relative to another IFR. Can the observer detect that some events that were in the previous IFR are missing in the new IFR? Again, this information can be described as a certain set of cause-and-effect relationships starting from an event that was not in this IFR. Or, in other words, as a set of states of the system that does not satisfy Equation (3). As discussed above, this is impossible. Now consider whether the observer can detect that there are some events in his new IFR that were not in the previous IFR. To do this, the observer must somehow be able to find out whether such an event was in the previous IFR. That is, it is necessary to find cause-and-effect relationships that are missing in the previous IFR and present in the new IFR. Or, in other words, find a set of states from Equation (3) that are present in the new IFR and are absent in the previous IFR. The new IFR does not have such information. It is impossible to obtain it from another IFR, as discussed above. Obtaining such information would mean that such information appeared in the IFR, but it cannot be there. Therefore, we conclude that the observer cannot detect that his new IFR lacks some events that were in his previous IFR.

By event identity, we mean that if some event occurred in one IFR, then it occurred in all IFRs. Here we do not claim that the properties of any event are the same in all IFRs.

We come to the conclusion that from the observer's point of view, events are the same in all IFRs, even if they are actually different due to the fact that Equation

(2) does not preserve events when moving between IFRs or is not satisfied at all. Or, in other words, from the observer's point of view, any event exists in all IFRs, even if the event actually exists only in a part of the IFRs.

This is the key result for constructing the hypothesis.

Note that this result does not depend on the hypothesis in any way. This result is true both for the case when Equation (2) preserves events and for the case when events are not preserved.

The key result for generalizing the causality principle is obtained: it does not matter whether events differ in different IFRs or not, but for an observer, it will always look like events in all IFRs are the same.

6. Application of the Principle of Causality and Human Existence

Let us assume that the fields in different inertial reference frames, having non-zero velocity relative to each other, are completely independent. When accelerating or decelerating, we would move to another reference frame, the fields in which would be completely independent of the previous one. In this case, if there is a person in one of the IFRs, there is no reason for him to be in any other IFR. Thus, a person could exist only in one IFR, and would disappear when his velocity changes. But this obviously contradicts everyday experience, when the velocity changes, our consciousness remains continuous, the body continues to exist. Based on this, there must be a limit on how much the fields and, accordingly, events differ in different reference frames.

Let us assume that when the relative velocity of the inertial reference frames tends to zero with respect to each other, the difference between applying the causality principle simultaneously to both IFRs and separately for each IFR must tend to zero. In this case, a certain dependence of the fields in different inertial reference frames appears on each other. With a sufficiently small difference in velocity between the reference frames, a change in velocity by a person will not lead to his disappearance in the reference frame that has become his new reference frame with zero relative velocity. This condition is necessary for the existence of a person.

This can be formulated as follows: when the relative velocity of two inertial reference frames tends to zero, the difference between applying the causality principle separately to each of these IFRs and applying the causality principle simultaneously to both IFRs must tend to zero. This is another postulate of the hypothesis, additional to the main assumption.

7. Types of Space-Time and Fields Transformations

Let us consider the transformations of space-time and fields that arise on the basis of the main assumption of the hypothesis.

According to the result obtained above, from the observer's point of view, each event exists in all IFRs, the principle of causality connects events in all IFRs. At the same time, in fact, events may differ, some events may exist in one IFR and be absent in another. Therefore, two types of transformations can be distinguished here.

The first type is the transformation of space-time and fields based on events observed in different inertial reference systems by observers who are stationary relative to the corresponding inertial reference systems.

The second type of transformations are transformations of space-time and fields from the observer's point of view. The observer may be motionless relative to one of the inertial reference frames, he may change his speed, but, according to the results above, for him any event appears as existing in all IFRs.

Let's consider these types of transformations and their differences from each other in more detail.

First, let us consider the transformations of space-time and events from the observer's point of view. The observer can observe only in the inertial frame of reference relative to which he is stationary. All information about events in other inertial frames of reference is indirect and is reconstructed on the basis of observations in the observer's frame of reference. The observer observes and, based on the results of observations, makes assumptions about what the transformations of space-time should be. The observer sees that the events he observes in one frame of reference also occur in other frames of reference. From this, the observer can conclude that if an event occurs in one frame of reference, it occurs in any other frame of reference. On the basis of such observations and the conclusions based on them, it is possible to construct transformations of space-time, fields, and the corresponding theory. Let us call this type of transformations observable transformations of space-time and fields.

The second type of space-time and field transformations are space-time and field transformations based on fields observed in different inertial reference frames by observers stationary relative to the corresponding inertial reference frames. As discussed above, it is impossible for observers to obtain information about events located in inertial reference frames moving relative to them and to compare them directly. Let us call this type of transformations direct space-time-field transformations.

From the basic assumption of the hypothesis, we obtained that there should be two types of transformations of space, time and fields.

The existence of two different types of transformations makes it impossible to use some single space-time continuum, where the transition between IFRs corresponds to a change of coordinates. In a single space-time continuum, it is impossible to obtain different events in different IFRs. Therefore, if the hypothesis is true, it points to the existence of something more fundamental than space-time.

8. Postulates of the Hypothesis

Now we can describe all the postulates of the hypothesis.

Postulate 1: The principle of causality applies separately and independently to each different inertial frame of reference.

This postulate is the basic assumption of the hypothesis.

This postulate is less restrictive than the usual principle of causality, which applies to events in all frames of reference. Therefore, adding this postulate does not restrict, but rather expands the hypothesis, compared to the existing principle of causality.

Postulate 2: As the relative velocity of two inertial reference frames tends to zero, the difference between applying the principle of causality separately to each of these inertial reference frames and applying the principle of causality simultaneously to both inertial reference frames must tend to zero.

It is not entirely clear whether this postulate can be considered as a separate postulate or simply a consequence of the previous postulate. It has already been shown above how this requirement arises. Therefore, it can be said that this statement is a consequence of the fact of human existence.

These postulates do not change the formulation of the principle of causality. Here we separate and modify the implicit postulate that events are the same in all IFRs from the principle of causality.

9. Hypothesis Testing Possibilities

The conclusion obtained above that, from the observer's point of view, events in all reference systems are the same, excludes the possibility of directly testing the hypothesis by comparing events in different reference systems.

There are physical theories that expect the same events in all frames of reference. If a collision of a pair of particles occurs in some frame of reference, then all modern physical theories expect that such a collision will occur in all frames of reference. It turns out that all modern physical theories agree with this hypothesis, although they satisfy only the transformations from the point of view of the observer.

One can try to find other ways to test the hypothesis. One way is to build a theory based on the hypothesis. And then you could test the predictions of such a theory.

A way to indirectly test the hypothesis is visible, to try to find upper and lower limits on how much events can differ in different inertial reference systems. How exactly to do this is not entirely clear, but some considerations can be made. A person changes his speed within fairly wide limits. At the same time, a person exists in all of these reference systems. Using this fact, and based on various models of how events change between inertial reference systems, randomly or otherwise, one can obtain an upper limit on how much events differ between inertial reference systems. Such an idea for indirect testing is found quite easily. This may mean that one can find a whole series of indirect ways to test the hypothesis.

Perhaps a detailed analysis will allow us to find ways to also find opportunities to test the lower bound.

10. An Example Where There Is a Difference in Events in Different IFRs

It is usually considered that an IFR is a certain coordinate system in space-time.

Accordingly, the transition between IFRs is just a change of the coordinate system. It is obvious that when changing the coordinate system in any space-time, any event existing in one IFR will also exist in other IFRs. This means that the principle of causality acts simultaneously for all IFRs, which is inconsistent with the hypothesis. Therefore, if the hypothesis is true, then the transition between IFRs cannot be just a change of the coordinate system in space-time. This means that there is something more fundamental than space-time.

When reading the hypothesis, someone may get the opinion that everything is formally correct, the hypothesis really does not contradict modern theories, but this formal logical correctness has nothing to do with real physics. Note that such an opinion rather means that the metaphysical picture of the world of such a reader contradicts this hypothesis. Therefore, this is a philosophical argument that should not be considered in science.

However, it will still be useful to show how this hypothesis can be used to build theories on its basis. First, we will give an example of some hypothetical universe where the postulates of the hypothesis are realized. We will show how it turns out that events in different IFRs can differ. Then we will consider how to build a theory based on the hypothesis in the general case.

Let's consider what properties the original model should have, and what we expect to get.

The initial model must be integral and allow mathematical description. We expect to obtain an infinite set of space-times. For each different inertial reference frame, there must be its own space-time belonging to this set. In each space-time belonging to this set, the principle of causality must be fulfilled. In this case, the principle of causality must be fulfilled independently for each space-time. Postulate 2 must be fulfilled, when the relative velocity of two inertial reference frames tends to zero, the difference between applying the principle of causality separately for each of these inertial reference frames and applying the principle of causality simultaneously to both inertial reference frames must tend to zero.

The requirement for the integrity of the original model here arises from the fact that as a result, we must obtain an infinite set of space-times, instead of the usual space-time continuum. Therefore, we must have something fundamental from which all space-times with fields on them are derived.

In each of the space-times, some laws of physics must be fulfilled. We require that the laws of physics be the same in all space-times. At the same time, for our purposes, it does not matter whether these laws of physics are similar to those known to us or not. The goal here is to show that it is possible to find a model in which the postulates of the hypothesis are fulfilled. Finding such an example will mean that it is possible to construct other models. And that, perhaps, in one of these models it is possible to obtain the same laws of physics that are known to us.

So, we are looking for a hypothetical universe in which the postulates of the hypothesis would be fulfilled.

Let's start with a simplified example. Let's consider the plane (x, y), with the field $f(x,y)=x+y$ defined on it. Obviously, nothing changes here, there is no time or dynamics.

Let us look for how to transform the space (x,y) into a set S consisting of space-times $((z,t),K)$, where z is a spatial coordinate, t is time, K is an inertial reference system to which the space-time (z,t) corresponds, and where Equation (3) is satisfied.

To do this, we take some transformation from (x,y) to (z,t) and check that Equation (3) holds there.

Consider the following transformation:

$$t=ky$$

$$z=x$$

Here t is a candidate for time, z is a candidate for space. We will find the inertial frame of reference corresponding to such a system of equations later. k is a certain coefficient, the meaning of which will become clear later.

Let's find how to calculate the field values at the point (z,t), knowing the values at the point (z,t_0), where $t_0=ky_0$. We find:

$$f(z,t)=f(x,ky)=x+ky=x+ky+ky_0-ky_0=(x+ky_0)+k(y-y_0)=f(z,t_0)+(t-t_0)$$

Time in physics equations is a parameter of change. We have obtained an equation where there is a parameter of change. This parameter can be called emergent time, since Equation (3) is satisfied. Space z can be considered an emergent space, because when t changes, changes occur in this space.

Thus, from a two-dimensional plane without time and dynamics we have moved to a one-dimensional space with time and dynamics, and found a candidate for an emergent space-time for some IFR. The parameter k can now be interpreted as a unit of time.

Now let's look for how to add transitions between IFRs to such a model. Let's rotate the previous space-time (z,t) by an angle a in the space (x,y), and go to (z',t'). Let's rotate both axes simultaneously. Let's assume that the time axis should always be perpendicular to the space axis. The equations change slightly after the rotation, but Equation (3) is still satisfied, there is a parameter of changes. Obviously, the distance between any two points belonging to z and z', respectively, changes uniformly and proportionally to the time interval t or t', and the rate of its change depends on the angle a. Therefore, we can say that a candidate for an inertial reference system has been found. Accordingly, the space-times (z,t) and (z',t') correspond to different inertial reference systems if their axes have a non-zero angle relative to each other.

Inertial reference systems must have some other properties that we are not considering yet. For now, the goal is only to show the idea of how to derive time without time and dynamics.

In the resulting equation, the state at the previous moment of time affects the state at subsequent moments of time. Therefore, we can talk about the emergence of the principle of causality. As a result, from the space (x,y) we moved to the set $((z,t),K)$, where for each IFR K there is its own space-time, for each of which Equation (3) is independently satisfied.

It is clear that the considered example with the field $f(x,y)=x+y$ is extremely simple and is given to demonstrate the ideas.

If the field $f(x,y)$ is more complex, it is possible to expand the field in some complete system of orthonormal functions so that the field at each point is equal to the sum of functions with some coefficients. For example, when expanding in a Fourier series, the function $f(x)$ can be represented as $f(x)=\sum_{k=-\infty}^{+\infty}\hat{f}_k \mathrm{e}^{ik\frac{2\pi}{\tau}x}$. Then check whether it is possible, with a parallel translation of the line over some distance l, to construct an equation for the change in the expansion coefficients of the form

$$\Phi(l)=A\Phi(0) \tag{5}$$

Here $\Phi(0)$ is the set of expansion coefficients in some system of functions, for each point for some selected line, l is the distance at which the line was transferred, $\Phi(l)$ is the set of expansion coefficients for each point for the selected line after its parallel transfer by a distance l. If such an equation can be constructed, then we can say that a candidate for space-time has been found. If it does not work, we go back and try another system of functions. In this case, it is not possible to find the required system of functions for every field. If the required system of functions is found, then we need to check that the same equations will work when the line is rotated by an arbitrary angle, so that we can talk about the existence of velocity. The transition to an IFR moving with some velocity relative to the previous one corresponds to a line rotation by some angle. The smaller the angle between the IFRs, the smaller the difference in velocity.

It can be noted that if after the rotation of the line the equations describing the evolution of the field expansion in the space-time under consideration remain unchanged, identical in all IFRs, then this will mean the sameness of the laws of nature in all IFRs and the absence of an absolute frame of reference. This sameness can be obtained if the field equation does not have distinguished directions. For the purposes of the example, the absence of an absolute IFR is not required, since there is no goal to construct a picture of the universe that is consistent with known physical theories.

From a space without time, where nothing changes due to the absence of time, we have moved to a set of space-times. We can say that in each of them we have some effective fields that describe the state and evolution of the system.

It is obvious that when a space line rotates, the field expansion coefficients, in general, cannot but change. In this case, the smaller the rotation angle, the smaller the changes. As we have already considered, the rotation angle between lines corresponds to some relative velocity. Therefore, we obtain that the smaller the relative velocity of the IFR, the smaller the changes in the expansion coefficients. It can be argued that in general, knowing the expansion coefficient before the rotation, it is impossible to calculate the coefficient after the rotation. This means that knowing the state of the effective fields in one IFR, it is impossible to calculate the state of the effective fields in another IFR.

In order for a reasonable observer to exist in such a universe, we postulate that a reasonable observer can exist in the space-time constructed in the manner described. It is clear that for an observer to exist, a number of other conditions must be met, which we will not consider here. For the purposes of constructing an example, the fundamental possibility of an observer's existence in such an emergent space-time is sufficient for us.

It is obvious that in the considered hypothetical universe consisting of a plane (x, y) with some smooth field $f(x, y)$, and where it is possible to construct space-time by the described method, the causality principle is applied independently for each IFR. It is obvious that the smaller the angle between the lines corresponding to different IFRs, the smaller the difference in the field expansion coefficients. Any events in such a universe must be described on the basis of the field expansion coefficients in some orthonormal system of functions. This means that in such a universe, the smaller the difference in velocities between two IFRs, the smaller the difference in applying the causality principle independently for each IFR and simultaneously to both IFRs.

So, we have found some hypothetical universe in which the principle of causality is fulfilled and the postulates of the hypothesis are fulfilled.

Looking at this example, one can show how to build theories based on the hypothesis under consideration, in general:

1) Postulate the existence of something more fundamental than space-time

2) Determine how we will obtain space-time and fields from what was postulated in the first step. In this case, it will be necessary to somehow either obtain or postulate the principle of causality. The principle of causality must be applied in accordance with the postulates of the hypothesis.

3) Next, it will be necessary to show that the resulting fields and properties of space-time correspond to the observed ones, including those of quantum physics.

We have fulfilled the first two points for a universe without time and dynamics. What other variants of something more fundamental there are is still unclear. Perhaps we can get something similar based on a universe with more than one time. Perhaps we can find something else, as yet unknown.

In any space-time, the transition between IFRs is just a change of coordinate system. Therefore, if the hypothesis is true, then space-time is not fundamental, there is something more fundamental.

11. Principle of Relativity

One of the key questions to analyze when examining this hypothesis is whether it is compatible with all of modern physics. As previously discussed, this hypothesis is fully compatible with any theory or physical principle that depends on causality and assumes the sameness of events across all inertial reference frames. The next question arises: does modern physics contain any theories or principles that either do not depend on causality or do not assume sameness of events across all IRFs? No widely accepted theories satisfying these criteria exist. However, one physical principle stands out, which may not rely on the assumption of events sameness across IFRs: Einstein's principle of relativity.

11.1. Detailed Analysis of the Principle of Relativity

The principle of relativity [2] [3] states that equations describing physical laws retain the same form in all IFRs. This principle imposes specific requirements on the structure of equations in space and time.

As established earlier, all modern, widely accepted theories describe processes exclusively from the observer's perspective. Beyond equations describing physics from the observer's viewpoint, the hypothesis introduces direct transformations of spacetime and fields. It predicts the existence of something more fundamental than spacetime. Consequently, there must be equations describing this something. Clearly, the principle of relativity cannot apply to such equations, as they describe structure more fundamentally than spacetime.

To illustrate this conclusion, consider the earlier example: the field $f\left(x,y\right)=x+y$, which is entirely time-independent. Thus, the principle of relativity cannot govern it.

A natural question arises: must the equations for direct spacetime and field transformations also satisfy the principle of relativity? Let us examine this.

The hypothesis does not require that the state of spacetime and fields at a given time in one IFR can be used to compute state of spacetime and fields in another IFR. Based on the given example, one can understand in which cases such a calculation is impossible. This occurs when the state of spacetime and fields in one IFR cannot uniquely determine the state of something more fundamental than spacetime. Therefore, direct transformation equations may depend not only on spacetime and fields across IFR but also directly on this fundamental something. We conclude that, in general, the principle of relativity does not apply to equations of direct transformation.

At the same time, we do not exclude the possibility that in some models it will be possible to calculate the state of space-time and fields at some point in time in one IFR to calculate the state of space-time and fields at some point in time in any other IFR. In such models, the principle of relativity can also be extended to the equations of direct transformations.

In the general case, only equations remain that describe the laws of physics from the point of view of an observer.

Therefore, the principle of relativity should be reformulated as follows: the equations, describing the laws of physics from the point of view of an observer, have the same form in all inertial reference frames. However, given the hypothesis, we do not mean here that events are the same in all IFRs.

A further question arises: must these equations have the same form in all IFRs objectively, or only from the observer's perspective? In other words, is it permissible for equations to differ between IFRs while appearing identical to observers?

Extending the reasoning applied to events across IFRs, it seems plausible that equations describing physics from the observer's perspective must be identical to the observer, but may differ between IFRs. However, it is unclear whether such a distinction is necessary for theories construction. A number of potential problems arise in developing theories where equations, describing physics from the observer's perspective, differ between IFRs, while looking the same for an observer.

11.2. Compatibility with the Reformulated Principle

Let us focus on the more compelling case where equations describing physics from the observer's perspective retain the same form in all IFRs. We verify whether the hypothesis aligns with this formulation of relativity.

To do so, we examine whether any constraints on these equations could conflict with principle of relativity. The hypothesis imposes two key limitations:

1) Equations must rely on the principle of causality, applied independently and separately to different IFRs.

2) As differences in events between IFRs approach zero (per the hypothesis, occurring when relative velocities approach zero), direct transformations must reduce to observer-dependent transformations.

No additional constraints are evident. We therefore conclude that the hypothesis is compatible with the reformulated principle of relativity.

Revisiting the earlier example, we see that equations describing physics from the observer's perspective must remain same across IFRs if the field equation defined on the (x, y) plane lacks preferred directions.

12. Conclusions

The application of the causality principle to inertial reference frames is considered. The hypothesis that the causality principle is applied separately and independently for each individual IFR is considered. The causality principle is a very fundamental physical principle, and it does not depend on other physical principles or any widely accepted physical theories. Therefore, when searching for possibilities for its modification, it can be considered completely independently, without relying on any other principles or widely accepted physical theories.

It was found that the observer has only the information that the IFR relative to which he is stationary has. Further analysis led to the conclusion that from the observer's point of view, any event exists in all IFRs, even if in fact the event exists only in a part of the IFR. These conclusions do not depend on this hypothesis.

This hypothesis leads to the fact that two types of transformations arise when switching between inertial reference systems. The first is the transformation from the observer's point of view. The second type of transformation is a new type of transformation, these are direct transformations of space-time and fields.

Since all modern widely accepted physical theories assume that if an event occurs in one frame of reference, it occurs in all frames of reference, this means that these theories satisfy only the transformations from the observer's point of view. This also means that the hypothesis does not contradict any widely accepted physical theory, but such theories describe only a special case.

Since the hypothesis predicts a second type of transformations that are absent from all widely accepted theories, this means that it is possible to construct a new class of theories that would take into account an additional type of transformations. If for the transformations of the first type, the transformations from the observer's point of view, we can say that they correspond to the transformations of STR and GTR, for flat space-time and for space-time with curvature, then there is no theory that would describe the transformations of the second type.

The exact form of direct transformations of space-time-fields cannot be obtained within the framework of this hypothesis. A deeper theory is required for this. Such a theory may lead to the prediction of new effects that can be experimentally verified. Therefore, it can be stated that this hypothesis is, in principle, falsifiable.

The principle of causality, as has been noted, is independent of any other physical principles and widely accepted theories. Therefore, the conclusions reached are in no way dependent on other physical principles and widely accepted theories. In other words, it is impossible to formulate any reasoned objections to this hypothesis using these other physical principles and widely accepted theories.

An example is given showing that it is possible to construct a model in which the postulates of the hypothesis are fulfilled.

An analysis of the possibility of testing the hypothesis was conducted. It was found that the hypothesis is, in principle, falsifiable.

The hypothesis predicts that space-time is not fundamental, there is something more fundamental. The hypothesis opens up the possibility of constructing a new class of theories.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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