Space-time and the source of the arrow of time

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Abstract: Physical processes are time asymmetric at the macroscopic level in favor of a forward arrow of time while it is believed to be theoretically time-symmetric at the microscopic level. A physical process (cause and effect) is intimately bound up with a physical system and a force that produces a change of the state of motion that characterizes the physical process. The change of the state of motion of a physical system is characterized by the change of its velocity; an important aspect of Relativity Theory (RT). It seems that space-time itself as described by RT must inevitably constitute a system that describes physical processes. Quantum mechanics (QM) implies space-time itself may be quantum in nature if QM is to comply with RT geometrically; i.e. Loop quantum gravity theory as a quantum space-time. I describe here space-time as a "discrete" system by which RT describes the motion of a physical system. Space, time and the forward arrow of time are described as the outcome of the interaction of space-time system containing such a discrete structure and physical systems such that the rules of RT are satisfied. Here, space, time and the intimate relationship between them are defined. Length contraction, time dilation and the forward arrow of time are explained accordingly.

Key words: Space-time; the arrow of time; time dilation; length contraction.

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1. Introduction

The theory of relativity (RT) transformed our understanding of space and time [1]. It may be easy to picture a three-dimensional space, but the nature of time has always puzzled scientists for very long as why time needs to accompany space in a unique way to describe motion. In other words, if a quantum space-time approach is to succeed, the puzzle of the nature of time and its intimate relationship with "discrete space" should be resolved. This requires describing time as discrete as well.

The prolonged inability for Newton's gravity to explain important aspects of gravitational phenomenon, most importantly action at a distance, led Einstein to blame space and time themselves for the apparent gravitational force and describe it as deformation in space-time. If gravity (as a force) was not to blame for the gravitational acceleration, then the other side is to blame; space-time. According to RT, there is a system with special properties called space-time that truly describes events in space and time. For example, in special theory of relativity (SR) if you are timing the duration of a lecture you will register the elapse of time differently than if you are in a room moving at a relative speed with respect to the room where the lecture is taking place. For the layman, this is simply because your watch then registers time slower than it would if you are timing the lecture in the lecturer room. In other words, when describing the duration of the lecture, if the second (time unit) in the lecturer room goes like "tick", the second in the moving room goes kind of like "teeck", a little longer. A meter stick held by the lecturer runs into a similar scenario, it is registered as shorter if you are doing the measurement in the other moving room. This is known as length contraction and time dilation which are described by Lorentz transformation when describing events happening in the lecturer room from the moving room point of view. Such a transformation necessarily requires unique properties of space-time system that allows light to travel at a constant speed of nearly $3 \times 10^8\ m/s$ no matter the relative speeds between the two rooms. This in turn rules out space-time as a "physical" system by normal standards (absolute reference frame). This is probably because any perceived system simply cannot mechanically resemble a light-carrier (luminiferous aether) system with mechanical properties that ensures the constancy of the speed of light as RT asserts in any inertial frame of reference. It is experimentally agreed to deny the need of an aether on the basis of the null results of Michelson-Morley experiment and its derivatives [2].

On the other hand, as much as RT is successful in describing events occurring at high speeds it imprints a huge gap with the other pillar of physics, Quantum Mechanics (QM), which describes "physical systems" at incredible precision and is characterized by the discreteness of physical systems.

The discrete geometry of space-time does not seem to contradict RT in its broad sense but it does not seem to be needed in the theory as the theory describes events that occur in space-time with regard to reference frames' relative velocities; a macro physical quantity that is less of a concern to a possible discreteness of space-time at the microscopic level. Simply by adopting the concept of discreteness of space-time to describe RT even though we know that this approach can be entirely overlooked to describe events in RT may be a proper approach to combine RT and QM [3]. The idea of quantum space-time was proposed in the early days of quantum theory by Heisenberg and Ivanenko as a way to eliminate infinities from quantum field theory. Quantum space-time may be employed to describe the quantum behavior of microscopic particles [4, 5].

Lorentz invariant quantum field theory is invariant under time reversal, validating CPT transformation, but as well-known observationally the flow of time must be in the forward direction only. Also, the psychological and thermodynamic arrows of time must always align [6] which leads to biological effect of the arrow of time. It is the goal of this paper to define the discreteness of space and describe the concept of the flow of time relying on relativistic approach; specifically to describe time as a physical quantity that describes space.

To do that, quantum space-time is adopted. Here, I will define a "system" of space of discrete nature, e.g., loop quantum gravity (LQG) is based on the insight of general relativity (Gr) that space-time is a dynamical field and therefore is a quantum object, and relate it to how RT describes events by choosing time as a numerical "dimension" from within the system. This is done by describing a proposed spatial unit to deform in the moving inertial frame as compared to local inertial frame. Here, we are just simply implying the exact approach of RT as space and time are deformed due to the relative velocities between any two inertial reference frames but here we take it another level; the deformation occurs at the unit level of space-time. In other words, if space is discrete and can deform as RT asserts, so would its spatial fundamental unit.

The mystery that links time with space as inseparable dimensions in describing events in space-time such that one of them must deform if the other one deforms has not been resolved. Here, time is described as a numerical factor that relates to the spatial dimension. It is proposed here that the forward arrow of time is the result of the inevitable constructional link between time (as proposed here) and space and therefore it follows that the introduction of randomness is the only thing which cannot be undone in any physical process. Here I will describe how RT might require a discrete, contractible space-time system to fully describe a relativistic event and how the forward arrow of time results from the link between space and time.

2. Space-time system

Space-time system is made of fundamental units that fill space (spatial units). The physical process of any system is constrained by the temporal and spatial behavior of space-time, hence by the rules of RT. Space-time and the arrow of time are defined as follows;

Space: In any direction, spatial length is defined by the distance that is made up by all the spatial units' sizes and specified by the dimension of the system.

Notion of time: Time is defined in the same way as we normally define the unit of time (second) as the duration of a periodic mechanism such as a pendulum in such a way that we can add up numerically the number of oscillations. Here it is defined by the number of the spatial units that are traversed by a moving object regardless of direction. If the object is moving at a constant speed then the number of traversed spatial units per unit length is invariable and the duration of time can be measured. This definition provides the root of the arrow of time.

Arrow of time: It specifies the forward direction of the increasing number of the spatial units while travelling in space irrespective of the direction of motion.

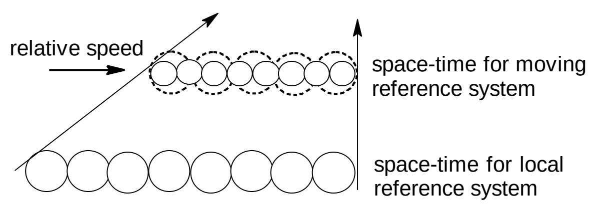
Space-time: It is the system that comprises the three dimensional spatial units and the time dimension (number of spatial units). This description of space-time integrates time with space as inseparable entities with equal weight of change, thereby a four-dimensional space-time of RT.

Contraction of space-time: Space and time can be described as contractible in the moving reference frame. We can stop short in that regard by just saying that as space contracts in Special Relativity (SR) so does the proposed fundamental spatial unit. Here we don't concern ourselves of how the relative velocity between the two inertial frames reduces the size of the spatial unit, we just describe the moving inertial frame as having contracted space when compared with the local inertial reference frame. If described "physically", contraction of space means reduction of the size of the spatial unit while contraction of time means reduction of the number of spatial units (inverse of the length of time unit as described by time dilation).

3. Results and discussion

3.1. Relative velocity causes time dilation and length contraction

In SR, length contraction and time dilation occur simultaneously (so RT's simultaneity is satisfied) with a magnitude-change that depends on relative velocity such that the speed of light remains constant relative to any inertial reference frame. Fig. 1 illustrates length contraction and time dilation due to an object moving at a speed relative to local reference frame.



1. Fig. 1. Mapping space and time from local reference frame to a moving reference frame defines length contraction and time dilation in RT.

In Fig. 1, mapping from a standard length unit and time unit from local reference frame to a moving reference frame defines length contraction and time dilation. It is proposed here that moving reference frame causes spatial units to contract in the direction of motion at equal weight for each spatial unit resulting in length contraction when compared with the standard length defined in the local reference frame. In SR, the magnitude-change of inverse of time (due to time dilation) is in the same order as the magnitude-change of length (length contraction). From Fig. 1 the relative change in time and length from local to moving reference frames is three units (time) and three unit sizes (length). Note that the number of spatial units in the contracted space (moving reference frame) per length unit (meter) remains the same since each spatial unit is contracted, which makes an observer in the moving reference frame observing the same number of spatial units (in the contracted length) but relative to the local reference frame the number of spatial units is reduced if compared with the local standard size of the spatial unit (dashed circles). It is to be noted that the magnitude of length reduction correlates to the relative velocity much the same as the reduction of the number of spatial units correlates to the relative velocity, which allows derivation of length contraction and time dilation in the same way as popularly derived in the literature. This results in time ticking slower since eight spatial units in the local reference system translates to five spatial units in the moving system (not to scale in the figure). Note that the contraction in the spatial unit is proportional to the relative velocity between the two reference frames in such a way that the constancy of the speed of light is preserved as a quality of space-time itself as RT asserts.

It can be noted that reversing the order of the two inertial frames produces the twin paradox. This brings space-time system of RT ever closer to QM as discreteness of space-time and the way time is defined here do not allow the reverse event to occur since quantum effects rule that reversing measurements makes no sense as measurement in the first order already kills the wave function (quantum mechanical arrow of time). The laws of QM rule with the collapse of the wave function mechanism.

The "relative" discrete description of space-time and contraction of its fundamental unit are two qualities of space-time that are not so obvious in RT which brings RT a step further to understanding relativistic quantum physics as well as quantum gravity.

3.2. The impact of the definition of time as a numerical value of space

The approach that geometry of space-time is quantized may have a great impact on our understanding of space-time as a quantized field, an important aspect of LQG theory that attempts to merge quantum mechanics and GR. The main prediction of LQG is space itself is discrete in nature, mimicking matter. In other words, the dynamic nature of matter is "interfaced" by the discrete nature of space-time of LQG, which projects a physical picture of space and time.

But SR does not shed the light on the nature of space and time as it only describes space-time as a single interwoven continuum that projects a dynamic nature of matter via Lorentz transformation of space and time with a common magnitude-change of time and space. It is puzzling as of why the magnitude-change is common for both aspects of space-time. Notice that magnitude-change by Lorentz transformation defined by Lorentz factor is the same for space and time if we define time as the frequency of spatial unit occurrence in an event rather than inverse of the frequency (duration) as commonly perceived (see Fig. 1).

The abstract definition of time as a numerical value of traversed space regardless of direction truly combines time and space as two aspects of the same quantity as RT asserts but it brings it down to the fundamental spatial unit.

3.3. Numerical definition of time and the arrow of time

The abstract definition of time as above ensures the forward directionality of time, e.g., if you are moving back and forth in a confined space then, unlike displacement, time adds up progressively by counting the number of all the traversed spatial units (scalar quantity).

The definition of time as the numerical value of the traversed spatial units for a moving object in space must increase with the traversing process and defines a basic irreversible process which explains the direction of time and agrees with the proposed arrows of time.

The most widely used arrow of time is the thermodynamic arrow which is based on the increasing entropy of isolated systems. If an isolated system is to exhibit motion by a thermodynamic process it should traverse more spatial units in space-time which simply adds to the time interval of the process. An increasing positive time interval defines an increasing entropy only. The numerical definition of time as above defines the second law of thermodynamics as a forward direction in time and therefore in space-time since space must follow suit (counting spatial units means traversing them). Also, spontaneously traversing the same exact spatial units that have been traversed in the exact reverse order is highly improbable; e.g., if you are blindly led from one location to another location by randomly choosing one path from a billion paths it is highly improbable to blindly choose the same path in the reverse process. This criteria of the rules of statistics and "dice playing" of space-time itself seems to be the leading mechanism in all arrows of time.

3.4. Statistical interpretation of time and space

Time here is described statistically as the frequency of occurrence of spatial unit while space as its size during the process of traversing a distance. Since SR asserts that the two variables of space and time describe the same event (pertaining to spatial unit) and correlate in the same way to the relative speed between the lab inertial reference frame and the moving reference frame, separation of the two variables is allowed and statistical treatment of one variable independently from the other is considered. This is clear as time dilation is dependent only on the relative velocity between inertial frames and the invariable speed of light. The distribution function of time in the velocity domain is simply derived from Lorentz factor $\gamma = 1/\sqrt{1-v^2/c^2}$, where the formula for determining time dilation is $\Delta t' = \gamma \Delta t$. From Fig. 2 it is clear that spatial unit can be squeezed to a limit such that the relative speed is limited to a maximum of that of the speed of light, a unique limitation property of space-time structure.

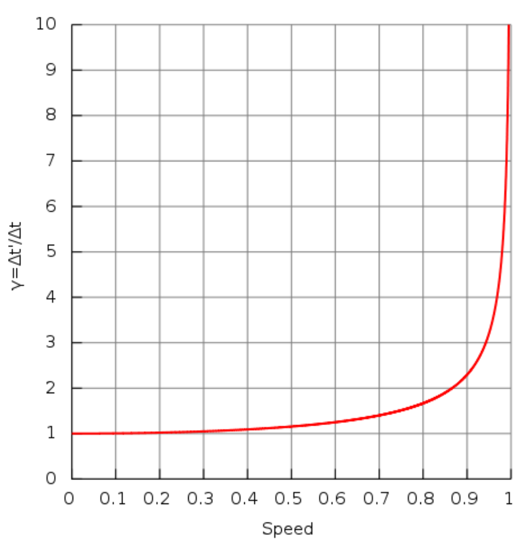


Fig. 2. Frequency distribution of time as a function of speed v ; speed of light c=1.

Defining the time as the frequency of occurrence of spatial units paves the way to a wider statistical treatment of an “ensemble of spatial units” of definite “energy levels” of space-time system as dealt with by LQG.

3.5. RT, time and QM

The apparent conflict between QM and GR has been recognized by Feynman in 1957 [7]. The conflict is mainly pronounced when we attempt to extrapolate QM superposition states to the macroscopic scale. Many authors have since refined and extended the discussion of this conflict [8-11].

In this paper, the abstract definition of time as above “interfaces” relational RT theory and “physical” QM. Here, time is defined as an integral scalar variable to a fundamental spatial unit of geometrical space-time. The definition added physical quality to the nature of a “spatial unit” that brought it ever closer to our understanding of quantum rules and integrating QM with geometrical RT. Specifically, time, subjected to Lorentz transformation, then can be defined as the coefficient that translates the length of the fundamental spatial unit at the microscopic level to a macroscopic distance as stated in the equation;

$$x = tl \qquad (1)$$

where l is the dimension (length) of the spatial unit in the direction of motion, t is the frequency of occurrence of the traversed distance, x is the total distance travelled.

This translational relation between microscopic space-time to macroscopic matter behavior combines time and space as one fundamental space-time aspect that characterizes both RT and QM theories. The “marriage” between the two theories may be achieved by a proper mapping, “interfacing” mechanism that preserves the fundamental principles of RT in a quantum space-time.

3.5.1. Uncertainty principle

The uncertainty principle is in the heart of QM, which states that certain pairs of physical properties of quantum particles pertaining to time and position, like position and speed, cannot both be known to high precision. I argue here that position and speed cannot be measured to arbitrary precision since both can only be measured one at a time, but can be extrapolated from each other. In this paper time and length are quantities defined as describing the fundamental spatial units, the number of the units as time and the total (sum) sizes of the units as distance, that are traversed by a quantum particle; i.e. travelling electron. A pair of physical quantities that pertain to the count and size of the spatial units cannot be measured with accuracy since measuring the sizes (length) of the fundamental spatial units scanned by a travelling quantum particle with certainty destroys the possibility to measure the count of traversed spatial units (time) simply because you need to traverse the same space-time path in reverse, a highly improbable process for a quantum system. This could simply be explained by that upon measurement the quantum particle disturbs the original quantum states of the space-time path, since space-time is described as quantum here with discrete units. In other words, uncertainty principle is the outcome of space-time being quantum.

3.5.2. Evolution of QM wave function vs. evolution of SR time-space

Since time as defined here describes the same spatial unit, upon measurement of either distance or time the other one can be extrapolated from the equation $x = tl$ with the same precision. Note that as defined here time and distance are two facets describing one "physical quantity", the spatial unit. This simply means, describing temporal behavior (momentum-dimension) suffices to describe any system. That is the case also when describing the system in terms of its displacement (energy-dimension). This is obvious from SR where Lorentz transformation gives exact time and distance evolution of an event with respect to the relative velocity between two reference frames, considering time as defined in this paper ($\Delta t' = \Delta x' = \gamma\Delta x = \gamma\Delta t$). In the same line, the kinetic and potential energies are transformed into the Hamiltonian which acts upon the wave function to generate the evolution of the wave function in time and space, with the Schrodinger equation gives the quantized energies of the system and gives the form of the wave function so that other properties may be calculated.

4. Conclusions

Following the principles of special theory of relativity, the nature of space-time is defined. By adopting a quantum discrete space with fundamental spatial unit, time is defined as the number of the spatial units that are traversed by a moving object regardless of direction. This numerical definition of time allows to safely identify time's arrow as only in the forward direction with a statistical unlikelihood for a reverse event to traverse its original path. The two predictions of relativity theory, time dilation and length contraction, were obtained qualitatively. The numerical adoption of the nature of time in space-time geometry will lead to a deeper understanding of space-time as a quantum system thereby a quantum theory of gravity is better approached in order to reconcile general relativity with the principles of quantum mechanics. This may lead to a promising ingredients of a fundamental physical theory. The forward arrow of time was identified as uniquely tied up with time as a scalar dimension. It is explained as due to the process that the number of traversed spatial units for a moving object in space must increase and hence define a basic irreversible statistical process.

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