The Continuous Nature of Time, Space and Spacetime: Challenging the Discrete Physical Theories

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Abstract

This paper argues for the continuous nature of time, space and spacetime, based on all observers' internal experience of the present moment as having zero duration and all observers internally experiencing always being in the present moment without any divisibility and discontinuity of this present moment and the logical consistency based on the space being the substratum for the existence of time. The implications of this continuity challenge the physical theories proposing discrete structures of space or time or spacetime, such as loop quantum gravity, causal set theory, etc.

1 Introduction

The nature of time, space and spacetime has been a fundamental question in physics. This paper presents a novel argument based on all observers' internal experience of the present moment as having zero duration and all observers internally experiencing always being in the present moment without any divisiblity and discontinuity of this present moment and, hence, argues for the continuity of time and using the logical consistency based on the space being the substratum for the existence of time, argues for the continuity of space and, thus, spacetime also.

2 The Fundamental Principle of Measurement: Detecting and Differentiating at least Two Events by the Measuring Apparatus

Any measurement of any physical quantity always requires detecting and differentiating at least two events by the measuring apparatus. This is a fundamental principle in the process of measurement. The following examples explain it in details.

Example 1. Two-Event Case at Classical Level: Measuring Time Interval Using a Stopwatch

For example, measuring a time interval using a stopwatch requires the stopwatch to detect and differentiate 2 events - the start event, when the stopwatch is started, and the stop event, when the stopwatch is stopped - to calculate the time interval between any two external events. The design of the stopwatch ensures it can detect the start and stop events to calculate the time interval accurately.

Example 2. Three-Event Case at Classical Level: Measuring Acceleration using an Accelerometer

An accelerometer [1] uses below 3 events to measure the acceleration of an object.

Event 1: Initial Position (Time t_0) - The position of the object at the initial time.

Event 2: Intermediate Position (Time t_1) - The position of the object at a later time.

Event 3: Final Position (Time t_2) - The position of the object at a further later time.

Measurement: Acceleration is calculated based on the change in velocity, which is derived from the positions at different times. The accelerometer must detect these three events to compute the change in velocity and, hence, the acceleration.

Example 3. Two-Event Case at Quantum Level: Measuring Electron Spin

Stern-Gerlach experiment [2] uses the following 2 events to measure the spin of an electron.

Event 1: Electron enters the magnetic field - The electron's path is influenced by the magnetic field.

Event 2: Electron hits the detector screen - The electron's deflection is observed on the detector screen.

Measurement: The deflection indicates the electron's spin state. The experimental setup is designed to detect these two events to measure the electron's spin.

Example 4. Three-Event Case at Quantum Level: Quantum Interference

Double-Slit Experiment [3] uses the following 3 events to measure quantum interference.

Event 1: Photon or electron passes through the first slit - The particle's path is partially determined.

Event 2: Photon or electron passes through the second slit - The particle's path is further determined, creating a superposition if it behaves like a wave.

Event 3: Photon or electron hits the detector screen - The particle's impact on the screen is observed.

Measurement The interference pattern on the screen results from the 3 detected events, showing the wave-like behavior of particles. The setup is designed to detect these 3 events to study the interference pattern.

This fundamental principle of measurement implies that there will be a minimum value of measurement for every physical quality which further implies that the continuity of any physical quality, even if it exists, cannot be established directly through its measurement. So, the continuity of time, if it exists, requires a non-measurement based logic which is being given in the next section.

3 The Proof for the Continuous Nature of Time

All observers always internally experience the present moment as "now" and as having zero duration as an integral part of their own continuous existence. Further, all observers internally experience always being in the present moment without any divisiblity and discontinuity of this present moment. This implies a seamless, unbroken flow of time as the present moment becomes the past moment and the future moment becomes the present moment in just one moment. If the present moment had a duration, even a tiny one, we could theoretically divide it in half. However, such a division feels nonsensical. Trying to pinpoint the exact start or end of the present moment is impossible as well as illogical as we perceive the passage of time as a continuous flow. The future continuously becomes the present and the present becomes the past. This suggests no breaks or gaps in the flow of time, which aligns with a zero-duration present. Also, imagine trying to measure the duration of the present moment. By the time you set up the measurement apparatus, the "now" you were trying to measure would have already passed. This highlights the difficulty in assigning a duration to the present moment. The past and future have a definite duration (even if the past may be finite and the future may be infinite). However, the present moment is fundamentally different, existing as a point without duration that separates these two. All these arguments establish that the present moment has zero duration.

This zero duration suggests that time is fundamentally continuous, as any discreteness in time would imply perceptible intervals between two consecutive moments which is not supported by the zero duration of the present moment always internally experienced by all observers in this universe. So, this provides strong experimental validation of the continuous nature of time.

The continuity of time is also supported by logical reasoning. A discrete model of time would introduce minimal temporal units, conflicting with our smooth, uninterrupted experience of the present moment. The zero-duration present moment not only provides experiential evidence but also maintains logical consistency with the concept of continuous time.

Also, it is important to note that the perceptual continuity of various discrete events such as seen in watching a video made of many discrete images or the perceptual continuity of the macroscopic objects made of discrete molecules is fundamentally different from the inherent continuous nature of time with every present moment being a part of the indivisible "now" in which all observers are always present and with zero duration and which is felt by all observers internally as an integral part of their own continuous existence. And whatever is the common experimental verification done by all observers in this universe, whether internally or externally, is an experimental/empirical evidence for its truth in physics only.

Established physical theories that align with experimental results, such as Einstein's theory of special relativity and general relativity, as well as Quantum Mechanics, all utilize a continuous model of time. These theories provide additional, independent experimental evidence for the continuous nature of time. The success of these theories in explaining and predicting physical phenomena further reinforces the argument for temporal continuity [4–6].

Einstein's theory of special relativity relies on the continuity of time to explain the constancy of the speed of light and the relativity of simultaneity. The equations of special relativity assume a continuous temporal dimension, and their experimental verification supports the continuous model of time [4].

Einstein's theory of general relativity describes gravity as the curvature of spacetime, a continuous fabric influenced by mass and energy. The continuous nature of time in general relativity is essential for accurately describing gravitational phenomena, as confirmed by numerous experiments and observations, such as the bending of light around massive objects and the precise orbit of planets [5].

Quantum Mechanics, despite dealing with discrete energy levels and quantized properties, operates within a framework of continuous time. The Schrödinger equation, which governs the behavior of quantum systems, assumes time as a continuous variable. The successful predictions and experimental confirmations of Quantum Mechanics provide strong evidence for the continuity of time [6].

4 The Proof for the Continuous Nature of Space

Space is the substratum for the existence of time as all events exist in space. Space provides the "arena" where events unfold. Without space, the concept of time wouldn't have meaning because there would be no context for events to occur. Imagine a single point without any "aroundness" - it's difficult to conceive of "before" or "after" in such a scenario. Time, in this sense, relies on the existence of space to be meaningful.

Without continuous space, the concept of continuous time loses its meaning, as events would not have a consistent spatial context. If space were composed of discrete units, any movement or change would occur in jumps from one spatial unit to the next. This would imply that time must also progress in discrete steps to match the spatial jumps, leading to a discrete temporal framework. For time to be experienced continuously, the spatial context in which events occur must also be continuous. A seamless flow of time requires that there be no gaps or intervals in space, allowing events to progress smoothly and uninterruptedly. So, the continuity of time establishes the continuity of space also. This is the strong and sufficient logic for the continuity of space.

Established physical theories that align with experimental results, such as Einstein's theory of special relativity and general relativity, as well as Quantum Mechanics, all utilize a continuous model of space. These theories provide additional, independent experimental evidence for the continuous nature of space. The success of these theories in explaining and predicting physical phenomena further reinforces the argument for spatial continuity [4–6].

In Einstein's theory of special relativity [4], Lorentz transformations rely on a continuous space and time framework. These transformations relate the coordinates of events between different inertial frames and predict phenomena such as time dilation and length contraction. The success of these predictions and their experimental verification through numerous high-precision experiments, such as the observation of muons traveling through the Earth's atmosphere [7], support the continuity of space and time. The relativity of simultaneity in special relativity demonstrates that the concept of simultaneous events depends on the observer's frame of reference. This relativity is only coherent in a continuous spacetime framework, where space and time are interwoven seamlessly.

Einstein's theory of general relativity [5] describes gravity as the curvature of continuous spacetime. The theory's equations, which predict gravitational effects, assume that space and time form a continuous manifold. The precise predictions of planetary orbits [8], light bending [8], and time dilation near massive objects [9] confirm the continuity of spacetime. The detection of gravitational waves, as ripples in the continuous fabric of spacetime caused by accelerating massive objects like merging black holes, further supports spatial and temporal continuity. The propagation of these waves through a continuous spacetime framework has been confirmed by experiments conducted by observatories such as LIGO and Virgo [10], providing strong evidence for the continuity of space and time.

Quantum Mechanics operates within a continuous spatial and temporal framework, even though it deals with discrete energy levels and quantized properties. The wave-like behavior of particles, such as interference and diffraction patterns observed in the double-slit experiment [3], requires a continuous space to be accurately described. The Schrödinger equation [6], fundamental to Quantum Mechanics, assumes continuous space and time variables to describe the probability amplitude of particles. It describes the wave function of a particle:

$$i\hbar\frac{\partial\Psi(\mathbf{r},t)}{\partial t} = \left[-\frac{\hbar^2}{2m}\nabla^2 + V(\mathbf{r},t)\right]\Psi(\mathbf{r},t) \tag{1}$$

where:

$\Psi(\mathbf{r},t)$ is the wave function,
$\hbar$ is the reduced Planck's constant,
m is the mass of the particle,
∇^2 is the Laplacian operator,
$V(\mathbf{r},t)$ is the potential energy.

The Laplacian operator in three-dimensional Cartesian coordinates is given by:

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \tag{2}$$

Above equations assume continuous time and continuous space. This continuous framework is essential for predicting and explaining quantum phenomena, such as electron behavior in atoms and chemical bond formation [11] [12].

5 The Continuity of Spacetime

Given the continuity of both space and time, spacetime must also be continuous. Spacetime, as the integrated entity combining space and time, relies on the continuous nature of its components to maintain a coherent and unified description of reality.

5.1 Spacial and General Relativity and Continuous Spacetime

Special and general relativity treat spacetime as a continuous manifold. The Lorentz transformations in special relativity and the Einstein field equations in general relativity both assume and require the continuity of spacetime [4,5].

The Lorentz transformations between two reference frames with the 1st reference frame moving with relative velocity v along x-axis are given by:

$$x' = \gamma(x - vt) \tag{3}$$

$$t' = \gamma\left(t - \frac{vx}{c^2}\right) \tag{4}$$

where $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

In general relativity, the Einstein field equations describe how matter and energy influence the curvature of spacetime:

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \tag{5}$$

where $G_{\mu\nu}$ is the Einstein tensor, $T_{\mu\nu}$ is the stress-energy tensor, G is the gravitational constant, and c is the speed of light [5].

6 Space, Time and Spacetime have a Minimum Measurable Value despite their Continuity

The fundamental principle of measurement, as explained earlier, says that any measurement of any physical quantity always requires detecting and differentiating at least two events by the measuring apparatus. Due to this principle, despite the continuity of time, space and spacetime, they will have a minimum measurable value.

In quantum mechanics and quantum gravity theories, the Planck time (t_P) and the Planck length (ℓ_P) are often referenced as the smallest measurable units of time and space, respectively [13, 14]. These units are derived from fundamental physical constants and represent scales at which our current understanding of physics breaks down.

The Planck time is the time it would take for light to travel one Planck length in a vacuum, and is given by:

$$t_P = \sqrt{\frac{\hbar G}{c^5}} \approx 5.39 \times 10^{-44}\,\text{seconds} \tag{6}$$

and the Planck length is defined as:

$$\ell_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1.62 \times 10^{-35}\,\text{meters} \tag{7}$$

where $\hbar$ is the reduced Planck constant, G is the gravitational constant, and c is the speed of light in a vacuum.

These values represent the scale at which classical notions of gravity and spacetime cease to be valid, and quantum effects dominate [14, 15].

The theoretical justifications for the minimum measurable value of time, space and spacetime are being given below:

1. **Uncertainty Principle:** Heisenberg's Uncertainty Principle implies a fundamental limit to the precision with which pairs of physical properties, such as position and momentum, can be simultaneously known. This principle suggests that there is a minimum measurable scale for time and space, reinforcing the idea that while time and space are continuous, their measurement is subject to quantum limitations [11]. Recent work has extended this to spacetime measurements [16].
2. **Black Hole Thermodynamics:** Theoretical work on black hole thermodynamics, particularly the Bekenstein-Hawking entropy formula, suggests a limit to the amount of information that can be stored within a given region of space [17, 18]. This further implies a minimum measurable space and time, although space and time themselves remain continuous [19].

The experimental evidences for the minimum measurable value of time, space and spacetime are being given below:

1. **Precision Measurements in Atomic Physics:** Advances in atomic clock technology and precision measurements of fundamental constants have pushed the limits of time measurement. These experiments confirm that while time can be measured with incredibly high precision, there is a practical limit imposed by quantum effects [20].
2. **Gravitational Wave Detectors:** Instruments like LIGO have achieved unprecedented sensitivity in measuring spacetime distortions [10].

3. **High-Energy Particle Physics:** Experiments at particle accelerators probe ever-smaller distance scales [16].

While time, space and spacetime are fundamentally continuous, the process of measurement imposes a minimum measurable value for these quantities. This is reflected in concepts such as Planck time and Planck length in quantum mechanics and quantum gravity theories. Both theoretical frameworks and experimental evidences support the idea that, despite their continuity, there are intrinsic limits to the precision with which time, space and spacetime can be measured [21].

7 Challenging the Emergent Continuity Concept

While some theories propose that continuous spacetime emerges from an underlying discrete structure at the Planck scale, the continuous experience of time and the experimental validation of the predictions made by various theories in physics using the continuity of time, space and spacetime such as special relativity, general relativity and quantum mechanics suggests that the continuity of time and, hence, space and, hence, spacetime is inherent and not emergent. Further arguments against the emergent continuity are being given below:

1. Scale problem: There is no clear mechanism explaining how discrete structures at the Planck scale give rise to the apparent continuity at observable scales.
2. Lorentz invariance: Many discrete approaches struggle to maintain Lorentz invariance, which is well-established in special relativity.
3. Quantum-classical transition: The emergence of classical continuous spacetime from discrete quantum structures faces the same conceptual difficulties as the general quantum-to-classical transition problem.

8 Challenging the Discrete Physical Theories

The arguments for continuous time, space and spacetime, along with there being a minimum measurement of time, space and spacetime at Planck scales as a part of the fundamental principle of measurement representing the limit of our current measurement capabilities rather than any fundamental discreteness of time, space and spacetime, and the arguments for the inherent continuity rather than any emergent continuity of time, space and spacetime automatically challenge the very foundation of all discrete physical theories which uses discrete time or discrete space or discrete spacetime given below and make case for the proponents of these theories to either counter these arguments given by the author or reconsider their theories:

1. Loop Quantum Gravity (LQG) [22]: LQG is an attempt to merge quantum mechanics and general relativity. It proposes that space and time are quantized at the Planck scale, represented by spin networks and spin foams and, thus, spacetime has a granular structure composed of discrete units. LQG suggests that space is composed of finite loops woven into an extremely fine fabric, with a minimum measurable area.

2. Causal Set Theory [23]: Causal set theory proposes that spacetime is fundamentally discrete and that the spacetime continuum emerges from a vast collection of discrete elementary events connected by causal relationships. It aims to reconcile quantum mechanics with gravity by discretizing spacetime while maintaining Lorentz invariance.

3. Quantum Graphity [24]: Quantum graphity proposes that space emerges from a more fundamental, discrete graph-like structure. It proposes that the universe started in a highly connected state and evolved to its current state through a phase transition.

4. Cellular Automata Models of Universe [25]: These models propose that the universe operates like a vast cellular automaton, with space and time discretized into a grid of cells that evolve according to simple, local rules. This approach attempts to explain complex physical phenomena emerging from simple, discrete underlying mechanisms.

5. Regge Calculus [26]: This theory uses a method for approximating general relativity using piecewise flat simplicial complexes, thus, treating spacetime as discretizable. It is originally a classical (non-quantum) approach.

6. Simplicial Quantum Gravity [26]: This theory approximates curved spacetime with flat simplices, creating a piecewise linear manifold. It

aims to provide a discrete formulation of general relativity that could be more amenable to quantization.

7. Causal Dynamical Triangulations (CDT) [27]: A approach to quantum gravity that discretizes spacetime into simplicial complexes and uses Monte Carlo simulations to study the resulting quantum geometry, aiming to show how classical spacetime might emerge from quantum fluctuations of geometry. Simplicial Quantum Gravity does not inherently enforce a causal structure but CDT explicitly maintains a causal structure by distinguishing between space-like and time-like edges in the simplicial complex.

8. Digital Physics [28]: This theory hypothesizes that the universe is fundamentally information-based and that all physical processes can be viewed as computations. It suggests that reality might be discrete at its core, analogous to the discrete nature of digital information processing.

9. Some Formulations of Quantum Einstein Gravity [29]: Some formulations of Quantum Einstein Gravity suggest an effective discreteness of spacetime at very small scales due to quantum effects. This approach uses renormalization group techniques to study how gravity behaves at different energy scales.

10. String-net Condensation [30]: While primarily a theory of emergent gauge fields and fermions, string-net condensation suggests that continuous space itself might emerge from the condensation of extended objects in a discrete spin model, providing a potential mechanism for the emergence of spacetime from discrete structures.

Addressing Potential Criticisms:

1. Quantum discreteness: Potential criticism: the success of quantum mechanics in describing discrete phenomena might extend to spacetime itself. Response: While quantum mechanics describes discrete phenomena, its mathematical framework (wave functions, Hilbert spaces) is continuous. Our theory proposes that this framework reflects a fundamentally continuous time, space and spacetime.

2. Singularity resolution: Potential criticism: discrete theories often claim to resolve singularities in general relativity. Response: The continuity of time, space and spacetime does not preclude other mechanisms for resolving singularities, such as limitations on spacetime curvature or energy density.

3. Measurement limits: Potential criticism: the existence of Planck-scale limits on measurement might imply fundamental discreteness of time, space and spacetime. Response: As argued in above section, measurement limitations arise due to the fundamental principle of measurement which states that any measurement of any physical quantity always requires detecting and differentiating at least two events by the measuring apparatus which implies a minimum value of any measurement. This does not necessarily imply the fundamental discreteness of time, space and spacetime.

9 Conclusion

The continuous nature of time, as evidenced by the zero-duration present moment, implies the continuity of space and spacetime. This continuity challenges all physical theories proposing discrete structures of time or space or spacetime such as loop quantum gravity and causal set theory and aligns with established physical theories like special relativity, general relativity and quantum mechanics. Thus, there is a need to develop those theories in quantum gravity which uses the continuity of time, space and spacetime and uses the limit of Planck time for the minimum measurement of time and the limit of Planck length for the minimum measurement of a spatial dimension. A few such theories are being discussed below:

1. Quantum Foam [14]: This theory suggests that at extremely small scales, spacetime has a dynamic, foam-like fluctuating structure due to quantum fluctuations, with virtual particles and miniature black holes constantly appearing and disappearing. This is part of the attempt to reconcile general relativity with quantum gravity. Quantum foam can be interpreted as continuous spacetime that experiences quantum fluctuations at extremely small scales, rather than being composed of discrete units.

2. Twistor Theory: [31] This theory aims to unify quantum mechanics and general relativity by representing spacetime points using mathematical objects called twistors. Twistor space is continuous. The theory reformulates physics in terms of holomorphic functions in complex projective space, which is a continuous mathematical structure. Twistor theory provides an alternative description of spacetime, rather than discretizing it. It relates points in Minkowski space to certain geometric objects (twistors) in a complex space. Twistor theory does not inherently contradict the notion of continuous spacetime. It offers a different mathematical framework for describing spacetime events, but this framework is itself continuous.

3. Group Field Theory (GFT) [32]: GFT is a quantum field theory, but instead of being defined on spacetime, it's defined on a group manifold (hence the name). The fundamental entities in GFT are fields that live on several copies of a group manifold. The excitations of these fields represent the quanta of space. The excitations of these fields are localised but that does not mean these excitations being an indivisible parts of the group fields will necessarily make the space or spacetime discrete. It is possible to interpret GFT in a way that maintains underlying continuity of space and spacetime, with the quanta representing indivisible excitations of a continuous group field. The author's critique of emergent continuity might still apply to some interpretations of GFT, but not necessarily to all of them.

10 The Implications for the Future Directions of the Quantum Gravity Research

The continuity of time, space and spacetime proposed in this paper has significant implications for quantum gravity research:

1. Reconciliation with quantum mechanics: Future theories must find ways to incorporate quantum phenomena within a fundamentally continuous time, space and spacetime, rather than discretizing either of these three.

2. Infinities in quantum field theory: The continuity of time, space and spacetime suggests that the infinities arising in quantum field theories

might be addressed through means other than imposing a minimum length scale.

3. Holographic principle: The continuous nature of time, space and spacetime may require a reinterpretation of the holographic principle in quantum gravity.

The future directions of the quantum gravity research should focus on:

1. Developing mathematical formalisms that can describe quantum phenomena within a continuous time, space and spacetime framework.
2. Investigating potential experimental tests that could distinguish between continuous and discrete time or space or spacetime theories at high energy scales.
3. Exploring the implications of continuous time, space and spacetime for other open problems in physics, such as the nature of dark matter and dark energy.
4. While current experiments cannot directly probe Planck-scale physics, indirect tests might be possible. For instance, studying the propagation of high-energy cosmic rays or searching for potential Lorentz invariance violations in extreme astrophysical environments could provide evidence for or against time, space and spacetime continuity.

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