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Time, a three-directional Dimension I

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Abstract

This paper revisits the concept of multidimensional time, extending discussions to incorporate orthogonal time dimensions θ and τ alongside the familiar linear t-axis, in resemblance to space and its intimate intertwinement with time. The presented framework explores how time's multidimensional nature might interact with spatial dimensions and quantum phenomena such as superposition and entanglement. Rather than redefining the arrow of time, this work underscores the need to broaden our perspective on time as multidirectional. By questioning certain conventional views about time's nature and representation, this model advocates for a forward-moving perspective that aligns with quantum mechanics. Though experimental validation remains a challenge, the model lays a foundation for further theoretical exploration and discussion.

Keywords: 3S + 3T; three-directional time; arrows of time; quantum mechanics; double-slit; experiment; entanglement.

1. Introduction

Time has been a fundamental concept in science and philosophy for millennia, and was traditionally understood as a linear, unidirectional flow along the t-axis in spacetime. However, this view has been challenged in the last century by scientists seeking a deeper understanding of time's true nature. This paper goes further, introducing a theoretical model where time is not a singular, linear dimension but a three-directional construct consisting of the familiar t-axis and two additional orthogonal time directions, θ and τ, as evoked in a precedent paper [1]. The framework is inspired by the intimate relationship between space and time, where time's evolution is intertwined with the spatial dimensions in the quantum realm. The presented model builds on previous discussions of multidimensional time, offering a fresh perspective that incorporates findings in modern quantum physics.

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Although we lack a direct sensory perception of time – or perhaps because of that – the arrow of time remains a contentious issue, with many debates focusing on its possible reversibility and the mechanisms behind its apparent unidirectional flow. Rather than revisiting these discussions, this work seeks to provide a broader perspective, emphasizing the multidimensionality of time itself.

The classical view of "absolute" time was thoroughly refined in the last century, significantly increasing the complexity of our time perception. In particular, the double-slit experiment, where the behaviour of electrons raises questions about causality, will be discussed. However, the most puzzling aspect of entangled electrons, often referred to as "Spukhafte Fernwirkung" or spooky action at a distance, still challenges both practical and theoretical physicists.

This paper highlights how these quantum phenomena can be interpreted through the lens of a three-directional time dimension, offering deeper insights into the interaction of quantum systems across both spatial and temporal dimensions.

2. The Arrow of Time: Entropy, Symmetry Breaking, and Quantum Perspectives

Time has long been viewed as a unidirectional flow, first articulated by Arthur Eddington in 1928, who linked it to the concept of entropy in his book: The Nature of the Physical World. This idea was reinforced over the past century through empirical observations of entropy and information loss, bolstering the notion of a unidirectional arrow of time. Notable work by David Bohm, interpreting quantum theory, further supports this view [2]. Additionally, the apparent asymmetries observed in cosmological evolution, particularly the Big Bang, are often cited as the "zero-time" event from which time is perceived to progress forward [3].

From a modern standpoint, the unidirectional arrow of time is often linked to symmetry breaking, a concept that plays a crucial role in quantum physics. In condensed matter physics, the phenomenon superconductivity illustrates this [4]. Similarly, in particle physics, symmetry breaking is fundamental for understanding particle interactions and helps explain why the universe is predominantly matter-dominated, as more particles than antiparticles were created during the Big Bang.

Symmetry breaking is often associated with entropy events. Yet, the arguments for a strictly unidirectional arrow of time face challenges, as entropy alone cannot serve as the universal qualifier for this view. While it is true that entropy tends to increase in a closed system, localized decreases in entropy can occur, creating "pockets" of order. Examples include the formation of crystals or the organization within biological systems [5]. Moreover, as many fundamental laws in classical mechanics are time-symmetric, a number of philosophers and physicists propose a bidirectional arrow of time. This viewpoint is supported by theories from Newton, Hamilton, Maxwell, Dirac, and Einstein's General Relativity, alongside Schrödinger's Uncertainty Principle. In recent times, Brian Greene suggested that entropy can increase both toward the future and the past from any given moment [6]. Other physicists, including Penrose (2005) and Carroll (2010), present similar viewpoints.

Recent advancements in quantum thermodynamics have further explored whether classical thermodynamic laws apply in quantum contexts. Gell-Mann and Hartle propose that the known arrows of time might be temporarily and locally reversed within isolated subsystems, though such scenarios are practically unfeasible Gell-Mann and Hartle [7]. Research by Elouard [8] highlights how entanglement and coherence can lead to non-classical behaviours, prompting a reevaluation of traditional thermodynamic principles. However, these effects are unlikely to manifest in macroscopic systems under ordinary conditions. Partovi demonstrates that the second law of thermodynamics and the thermodynamic arrow are emergent properties that depend on low-entropy environments Partovi [9]. His work on entangled macroscopic systems suggests that heat flow from a colder to a hotter system might imply a reversal of the thermodynamic arrow under specific entanglement conditions. However, the efforts necessary to realize these results may not lead to definite conclusions.

In contrast to traditional views rooted in entropy and symmetry breaking, some philosophers and physicists propose that the flow of time is driven by events. In their view, without events, time wouldn't "flow" at all. Instead of time being an independent force that unfolds in a pre-determined direction, it emerges as a consequence of what takes place [10].

Another key consideration that supports the unidirectional arrow of time is causality. As philosopher Hans Reichenbach notes, "A definition of time demands a distinction between cause and effect" [11]. This perspective is explored in further detail below. Still, we comp must ask: are these arguments sufficient to assert that the arrow of time is strictly unidirectional?

The concept of the arrow of time becomes even morelex when questioning whether time itself truly exists. Various physicists and philosophers challenge conventional perspectives: For instance, Barbour argues that time, as commonly understood, does not exist [12]. Similarly, Leibnitz remarked, "Space does not exist in any conventional sense. I may add the same turn of phrase for time." Maudlin critiques the notion of an objective flow of time, advocating for a block universe where past, present, and future coexist equally [13]. Einstein expressed a similar sentiment in a letter to Michele Besso, “The distinction between past, present, and future is only an illusion, however persistent" [14]. Minkowski took this further, asserting, "Henceforth, space by itself, and time by itself are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" [15].

How might this variety of insights shape our understanding of time and its arrow? How can they help us answer the fundamental questions: What is time, and how can it most intelligibly be represented?

3. The Double-Slit Experiment

According to de Broglie’s hypothesis, every moving particle, including multi-particle systems, is associated with a wave characterized by its wavelength. For macroscopic objects, this wavelength is negligible, but for microscopic particles like electrons, it becomes significant and manifests as wave-particle duality. The de Broglie wavelength is calculated as:

$$\lambda = \frac{h}{p}$$

with λ as the wavelength, h the Planck constant, and p the particle's momentum. This equation illustrates how a particle's wavelength diminishes with increasing momentum. This relationship forms a cornerstone of quantum mechanics.

In quantum mechanics, particles like electrons are described by wave packets. This description reflects the probabilistic description of their position, at the same time allowing for both particle- and wave-like behaviours. When an electron approaches a barrier with two slits, its wave characteristics dominate, governed by its de Broglie wavelength. Upon encountering the slits, the electron's wave packet diffracts, but when it reaches the detection screen, its particle nature emerges, localizing the electron to a specific position as described by Schrödinger's Uncertainty Principle [16].

The famous double-slit experiment exemplifies wave-particle duality in quantum objects. When electrons pass through the two slits without observation, an interference pattern forms, reflecting their wave nature. On observation, however, the interference pattern disappears, and the electrons behave like particles. This phenomenon, known as wave function collapse, highlights the pivotal role of observation in quantum mechanics and underscores the role of observation in determining quantum outcomes.

Recent advancements, such as those by Fein and his colleagues demonstrate such patterns even with molecules exceeding 25,000 atomic mass units, challenging the classical-quantum boundary [17]. Moreover, time-resolved experiments, such as those by Jin and his colleagues have further explored the evolution of interference fringes, providing new insights into quantum measurement and interference [18].

Adding to the complexity, Wheeler's delayed-choice thought experiment challenges our understanding of quantum measurement. [19] In this scenario, the decision to observe the electron's path is made *after* it has passed through the slits. However, since the electron behaves as a wave also after passing the slits, the wave function will collapse upon observation preserving causality. This is in accordance with the Copenhagen interpretation, stating that measurement causes the wave function to collapse into a definite state. Nonetheless, the experiment emphasizes the profound role of observation in shaping quantum reality, prompting deeper questions about the nature of time.

4. Quantum Mechanics in a Three-directional Time Framework

In the standard view of quantum mechanics, time progresses along a single axis t, moving from past to future. Expanding beyond this traditional view of time, a three-directional framework envisions time as comprising three orthogonal components: t, θ, and τ, which represent complementary temporal directions evolving synchronously with t [20]. These axes are described as follows:

t: The traditional temporal direction (past → present → future).
θ and τ: Two orthogonal, non-communicating time directions forming a two-dimensional "time plane" that synchronizes with the present ($t = 0$).

As time progresses from one moment to the next (e.g., $t_0 \rightarrow t_1$), the $\theta\tau$-plane shifts synchronously with t, maintaining a dynamic relationship with the present. This concept is illustrated below:

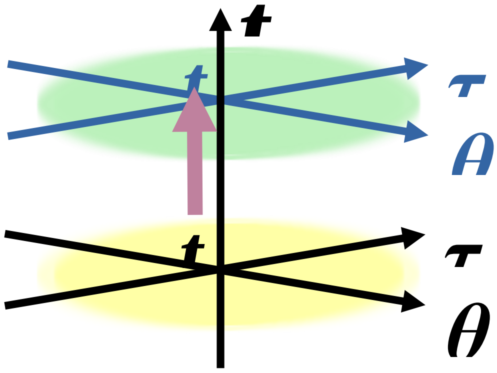

Figure 1: synchronous shifting of the $\theta\tau$-plane as t progresses from t_0 to t_1

Imagined as a projection of the future cone, the $\theta\tau$-plane organizes potential events within a two-dimensional framework. While these projections simplify the visualization of potential outcomes, they raise questions regarding event probabilities and superposition. For instance, reducing a three-dimensional structure (the future cone) into two dimensions may result in overlaps or ambiguities in event coordinates. These mathematical and conceptual challenges, though significant, fall beyond the scope of this essay and will be addressed in future work.

The future cone in the illustration below contains all possible events, while the past cone comprises realized events. The progression of time along the *t*-axis is understood as the addition of events from the future cone, which contains all possible events, into the past cone. These transitions occur through the "Present Gap", which probabilistically filters potential events in the future cone before passing the gap into the past cone (Muchow 2020).

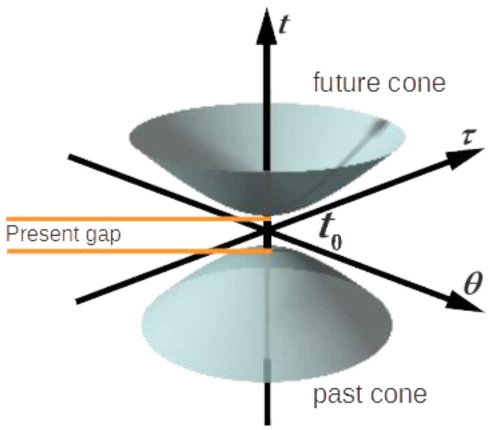

Figure 2: Present Gap Between the Past and Future Cone

This model provides a structured interpretation of time's flow, where the Present Gap allows the integration of potentialities into realized events. The insights derived from this framework may contribute to broader discussions in quantum thermodynamics, particularly in reevaluating the relationship between the laws of thermodynamics and the arrow of time [21].

Within this model, Wheeler's delayed-choice experiment must be reinterpreted as an interaction between the particle's wave function and the temporal directions. Unlike conventional interpretations confined to the *t*-axis, the wave function's collapse extends to the $\theta\tau$-plane, introducing a layer of temporal complexity. Such an interaction ensures coherence across all temporal directions, linking the particle's spatial state with its temporal configuration. This alignment integrates spatial and temporal states, opens up new insights into quantum behaviour.

The temporal aspect must also be extended to the spatial components of the measurement apparatus [22]. Measurement collapses the wave function both spatially—determining the particle's position on the screen—and temporally, influencing its evolution along all three temporal axes. Thus, the collapse is not only realized in *t*, but also in the $\theta\tau$-plane, ensuring synchronization of the wave function at the moment of measurement. Further on, the particle's state is established consistently across all temporal directions, aligning its past and future states probabilistically with the observer's present. The interplay between the wave function and the temporal aspects of the measurement system may also provide insights into apparent retrocausal effects observed in quantum mechanics, where the choice of measurement appears to influence the system's past state.

Since the wave function of a particle in this framework depends on all three temporal directions as well as its spatial coordinates, it can be expressed as:

$\psi(x, y, z, t, \theta, \tau)$

where, x, y, z describe the particle's position in space, while t, θ, and τ govern its time evolution. This representation encapsulates the coupled nature of the temporal axes, where each direction influences the particle's behavior in a synchronized manner. Considering the interplay of these time directions enables a deeper understanding of phenomena such as causality, potentiality, and the probabilistic distribution of events across all temporal axes.

This approach introduces the possibility of interpreting quantum phenomena, such as entanglement, along orthogonal time directions, associating varying probabilities with each axis. In this model, a particle's quantum state evolves not only in space but also across three interconnected time directions. The $\theta\tau$-plane, evolving synchronously with *t*, shapes the particle's overall behavior in time. As time progresses (e.g., from t_0 to t_1), this dynamic interplay adds a layer of complexity to the particle's evolution, diverging from the traditional treatment of time as a single linear direction.

In conventional quantum mechanics, the Schrödinger equation governs the evolution of the wave function in a single time direction. However, to accommodate the proposed three-directional time system, the equation must be extended to include dependencies on θ and τ. This modification introduces a new formulation of the Schrödinger equation, governing wave function evolution across all three temporal axes:

$$i\hbar\frac{\partial}{\partial t}\psi(x,y,z,t,\theta,\tau) = \hat{H}\psi(x,y,z,t,\theta,\tau)$$

In this model, a particle's wave function evolves in both space and time. For example, in a double-slit experiment, a single electron's wave function at each slit would depend on its spatial coordinates (x, y, z), and all three time coordinates (t, θ, τ). Denoting the wave functions at the slits as $\psi_{\text{slit 1}}$ (x, y, z, t, θ, τ) and $\psi_{\text{slit 2}}$ (x, y, z, t, θ, τ), the total wave function becomes the superposition of these two components:

$$\psi_{\text{total}}(x, y, z, t, \theta, \tau) = \psi_{\text{slit 1}}(x, y, z, t, \theta, \tau) + \psi_{\text{slit 2}}(x, y, z, t, \theta, \tau)$$

This superposition encapsulates the particle's spatial probabilities while incorporating its temporal evolution across all three time directions. The resulting oscillatory distribution will depend on the relative phases of the time directions, potentially manifesting as interference effects on the detection screen. These effects may result from a combined interference involving both space and time, where the particle's spatial probability determines its localization, while the three time directions could reveal as yet-undetected patterns of interference.

Just as Space allows for superposition in quantum mechanics—particularly when considering the electron as a wave packet—Time may also permit superposition, where different time directions influence measurement outcomes. In this view, the wave function does not merely propagate forward along t but also exhibits interference across the $\theta\tau$-plane.

Could such phenomena have been subtly present in Thomas Young's 1803 double-slit experiment with light? Or in Claus Jönsson's 1961 experiment, which first demonstrated double-slit interference with electrons?[23] Akira Tonomura and his colleagues used these foundational studies as basis for vividly demonstrating quantum interference in electron diffraction [24]. Still, the answer to the question is pending whether time-dependent diffraction effects were detected in these experiments.

The aim of this model is not to propose additional time directions arbitrarily, but to explore whether the temporal directions θ and τ might cause the electron's wave function to evolve in ways not yet observed. We certainly have seen all that current experimental tools can reveal. However, it is essential to consider that the observed diffraction patterns may not be solely influenced by spatial variables, but also by the temporal evolution of the system. If this model is sound, entirely new interference effects could become observable with advanced experimental techniques specifically designed to account for the proposed temporal directions.

4. Entanglement

Entanglement remains one of the most fascinating and counterintuitive phenomena in quantum mechanics. First theorized by Einstein, Podolsky, and Rosen (EPR) in 1935, it describes a situation where two or more particles become so deeply correlated that observing the state of one instantly determines the state of the other, regardless of the distance between them [25]. This phenomenon, famously dubbed "Spukhafte Fernwirkung" (spooky action at a distance) by Einstein, was experimentally confirmed in 1972 through Clauser and Freedman's photon-based tests[26]. Further milestones included the entanglement of beryllium ions at NIST in 1995 [27] and the successful entanglement of electrons at the University of California, Santa Barbara, in 1998 [28].

Recent experiments, such as the Einstein-Podolsky-Rosen demonstration with two spatially separated Bose-Einstein condensates, provide macroscopic evidence of quantum correlations. Colciaghi and his colleagues observed strong correlations between the collective spins of the condensates, affirming the EPR paradox and its implications for bridging the classical and quantum boundaries [29].

The mathematical framework of entanglement highlights its unique properties. For two entangled particles, their joint state is described by a single wave function, $\Psi(r_1, r_2, s_1, s_2)$, where r_1 and r_2 denote the spatial coordinates, and s_1 and s_2 represent the spin states of the particles. This wave function can be expressed as a product of spatial and spin components:

$$\boldsymbol{\Psi}(\mathbf{r_1}, \mathbf{r_2}, s_1, s_2) = \psi_{\text{spatial}}(\mathbf{r_1}, \mathbf{r_2}) \cdot \chi_{\text{spin}}(s_1, s_2) \quad \text{[equation (1)]}$$

where, r_1 and r_2 describe the spatial coordinates of the two particles, while s_1 and s_2 describe their spin states. Notably, this joint wave function cannot be factored into independent components for each particle.

Upon measurement, the wave function collapses, revealing the characteristics of the observed particle while instantaneously determining the corresponding properties of its entangled partner. This result respects the Pauli Exclusion Principle, which states that two spatially close fermions, such as electrons, cannot occupy the same quantum state.

The above equation (1) reflects the fact that the spin state of an electron can be written as:

$$\psi = a|\uparrow\rangle + b|\downarrow\rangle$$

where a and b are complex. For a two-particle system, the joint state is described as the tensor product of their individual states, probability amplitudes, and $|a|^2$ and $|b|^2$ represent the probabilities of the corresponding states. With $|\psi A\rangle$ and $|\psi B\rangle$ for particles A and B, respectively, the joint state is:

$$|\psi\rangle = |\psi A\rangle \otimes |\psi B\rangle$$

In the case of entangled particles, this simple separability no longer holds. Instead, the system is described by maximally entangled states, such as the Bell states [30]:

$$|\Phi^+\rangle = (|\uparrow\rangle \otimes |\uparrow\rangle + |\downarrow\rangle \otimes |\downarrow\rangle)$$

$$|\Psi^-\rangle = (|\uparrow\rangle \otimes |\downarrow\rangle - |\downarrow\rangle \otimes |\uparrow\rangle)$$

These states show that measurement of one particle immediately defines the state of the other, with perfect correlation. This correlation highlights, irrespective of the distance between the particles, the non-local nature of quantum entanglement. The probability of any given outcome is determined by the Born rule:

$P_{(outcome)} = |\langle\psi|\Phi\rangle|^2$

Thus, the collapse affects both particles in an entangled pair simultaneously, based on the measurement of one particle's state.

To better visualize this, consider the following figure, which illustrates the spatial separation of the entangled particles over time:

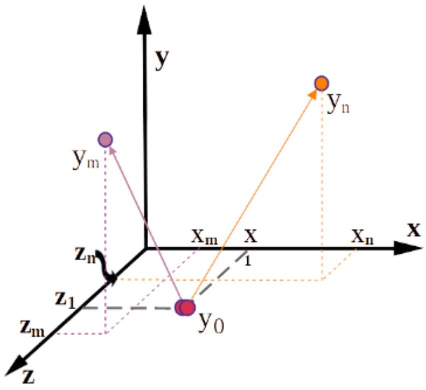

Figure 3: spatial representation of separating entangled electrons

The figure illustrates an entangled electron pair initially located at position x_1, y_0, z_1. The arrows indicate their displacement as they separate over time. After a time interval $\Delta t = t_2 - t_1$, the electrons are found at positions x_n, y_n, z_n and x_m, y_m, z_m, respectively.

Applying the conditions of the presented time model, the separation of the electrons in time can be depicted as follows:

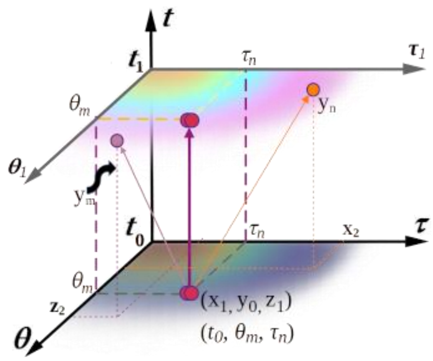

Figure 4: temporal representation of entangled electrons

At t=0, the time coordinates of the entangled electron pair are t_0, θ_m, and τ_n, corresponding to the spatial coordinates x_1, y_0, z_1. The evolution of the entangled electrons in time can be viewed in two ways:

a) The entangled pair moves together in time, without separating, to their new coordinates t_0, θ_m, and τ_n, or

b) Alternatively, the spatial separation of the electrons is mirrored by a corresponding separation along the temporal axes axes θ and τ of the Time dimension.

In either interpretation, the electrons ultimately arrive at the same level within the three-directional time framework, remaining entangled both spatially and temporally. If observed at t_1, the wavefunction collapses not only in the spatial, but also in the time coordinates over the $\theta\tau$-plane, revealing the characteristics of both particles for the observer instantly, at this moment t_1.

The persistence of entanglement, even across spatial separation, finds an elegant explanation within this three-directional time framework. By incorporating additional temporal axes, the model offers a comprehensive perspective on quantum correlations, suggesting that entanglement extends seamlessly across both spatial and temporal directions. This approach deepens our understanding of the intricate interplay between space, time, and quantum phenomena.

5. Conclusion

In this essay a novel model of time is propose, extending beyond the conventional unidirectional flow by introducing two additional orthogonal directions, θ and τ. Together with the perceptual time axis t, these axes form a three-directional time plane anchored at a “floating” point representing the present. Although 3S + 3T frameworks are not yet widely recognized, they offer a fresh perspective on the evolution and entanglement of particles across both spatial and temporal dimensions.

The presented approach challenges traditional notions of simultaneity and causality, suggesting that our understanding of temporal relationships requires re-evaluation. By positioning quantum entanglement as not merely a spatial phenomenon but an inherently temporal one, this model opens new conceptual pathways for understanding particle interactions at a deeper, unified level.

As discussed, current debates about the arrow of time have done little to advance our understanding of what time truly is or how it is structured. While the double-slit experiment inspires bold hypotheses, much work remains to validate the predictions made by this model. A key challenge lies in the limitations of current experimental tools, which may be insufficient to detect the fine or hyperfine structures in interference patterns that could result from time-related effects.

The most compelling support for a three-directional time framework arises when viewing "Spukhafte Fernwirkung" (spooky action at a distance) through this lens. This model provides an elegant and coherent explanation of quantum entanglement across both spatial and temporal axes, addressing a puzzle that has long challenged physicists.

Future research could explore how this three-directional approach to time interacts with established theories in quantum mechanics, relativity, and cosmology. Developing suitable experimental methods to test the effects of the $\theta\tau$-plane in quantum systems could push the boundaries of both theory and practice.

Ultimately, conceptualizing time as three-directional invites us to reconsider not only our physical models of the universe but also the limits of human perception. If time is truly multidirectional, this insight might profoundly alter our understanding of causality, free will, and the fundamental nature of reality itself.

The questions raised by this model offer exciting avenues for further exploration, inviting robust debate about aspects of the universe that may yet lie beyond our full comprehension.

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