Explanatory Depth:
The Integration of
Relativity, Quantum Theory and Cosmology

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Abstract

Foundational tensions between General Relativity-Quantum Gravity and Special Relativity-Quantum Mechanics and unresolved cosmological issues remain significant barriers to achieving explanatory depth in theoretical models. Without ad hoc assumptions, fine-tuning, or perturbative techniques, this analysis evaluates the explanatory depth of an integrated ontological and dynamic model that addresses these issues based on a single set of uniform laws across scales.

The explanatory framework, built on a fully relativistic, discrete 4D spacetime coupled to an ontic, high-dimensional counterpart, integrates the physical laws of General and Special Relativity with quantum phenomenon. It reconciles quantum effects, such as entanglement, nonlocality, quantum collapse, and instantaneity within relativistic constraints. It also explains cosmological gravitational challenges, including singularities, regularization, background independence, gravity's relational, local spacetime curvature, and the black hole paradox.

The framework provides a novel perspective on cosmology and cosmogony, explaining the physical connection between the quantum collapse of 4D spacetime at Heat Death and its instantaneous re-emergence at $t = 0$. The pre-existing intrinsic energy density of the discrete substructures that form spacetime and its high-dimensional counterpart is identified as the source of the cosmological constant (Λ). Additionally, the model examines quantum path irreversibility and the arrow of time through the dynamics of quantum state evolution and instantaneous collapse.

Mathematically, the analysis is supported by a set of universal physical laws, including discrete Maxwell, Dirac, and Klein-Gordon equations, a modified Regge Calculus for discrete spacetime, discrete Einstein Field Equations for a curved, discrete spacetime, and laws governing quantum state evolution and collapse.

Keywords: Explanatory Depth, General Relativity, Special Relativity, Quantum Gravity, Quantum Mechanics, Discrete 4D Spacetime, Quantum Collapse, Cosmological Constant, Background Independence

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Table of Contents

1. **Introduction**

1.1. Explanatory Depth

Explanatory depth is an essential tool for evaluating the validity of theories that address the general relativity-quantum gravity (GR-QG) and special relativity-quantum mechanics (SR-QM) tensions, as well as the physical and theoretical issues associated with the universe's cosmogony and cosmology.[1] Resolving the GR-QG and SR-QM tensions has proven so intractable that few theories comprehensively engage with them, and those that do often rely on complex mathematical constructs that conflict with the constraints of GR and SR. While cosmological issues related to the emergence of 4D spacetime at $t = 0$, the cosmological constant, and the arrow of time have been addressed directly by a number of theories, no consensus has yet emerged.

Without ad hoc assumptions, fine-tuning, or perturbative techniques, the DO model examines a novel ontological and dynamic framework that integrates a fully relativistic, discrete 4D spacetime with an ontic, high-dimensional counterpart. Phenomena across all scales and domains are based on a single set of uniform physical laws.[2]

1.2. Sub-atomic, Macroscopic, and Cosmological Scales

A critical measure of a model's explanatory depth is its ability to unify ontology, relativistic dynamics, and physical laws across sub-atomic, macroscopic, and cosmological scales. Models that address the GR-QG and SR-QM tensions, as well as the universe's cosmogony and cosmology, must reconcile the ontology and dynamics of quantum states[3] with GR and SR while accounting for quantum experiments that challenge these frameworks.

At a minimum, any theory that addresses the SR-QM tension in a relativistic context should include 1) quantum entanglement and nonlocality, 2) the instantaneity of quantum collapse, 3) causality, 4) the nature of time, 5) space-like separation, 6) separability, 7) indeterminism, 8) quantum state emergence and annihilation, 9) quantum state localization, 10) unitarity, 11) quantum tunneling, 12) the relativity of simultaneity, 13) relativistic energy increase, 14) quantum non-attenuation and quantum exclusivity, 15) the Born Rule's relationship to SR, 16) the ontic representation of N-body quantum states in 4D spacetime and 17) the quantum-classical divide.

Theories addressing the GR-QG tension should include 1) cosmological and black hole singularities, 2) regularization, 3) background independence, 4) the nature of time, 5)

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[1] See generally, (Ylikoski & Kuorikoski, 2010); (Wolf & Thebault, 2023); (Azhar & Loeb, 2021).
[2] See Appendix A for discrete mathematical formalisms.
[3] Under the DO model, subatomic entities are quantum states, not particles. Mathematical wavefunctions describe the evolution and collapse of all quantum states but are not ontic. (Maudlin 2013b, 2019); (Monton, 2006); (Pusey et al., 2012). For alternative views, see (Albert, 2013), (Chen, 2019), and (Ney, 2021, 2023).

non-locality, entanglement, and instantaneity, 6) gravity's quantizability, and 7) the black hole information paradox.

Finally, theories that address the universe's cosmogony and cosmology at or near t = 0 should include 1) the emergence of 4D spacetime, 2) its near homogeneity and isotropy, 3) the horizon and causality problem, 4) the flatness problem, 5) gravitational entropy approaching zero 6) the cosmological constant and dark energy problem, 7) global energy conservation and 8) the arrow of time.

1.3. 4D Spacetime's Incompatibility with Current Quantum Theories

Neither SR nor GR, developed in the early 20th century, directly addresses QM, and later efforts to integrate GR-QG and SR-QM remain largely unsuccessful. Quantum frameworks such as Schrödinger's wave mechanics, Heisenberg's matrix mechanics, and most versions of Feynman's path integral rely on non-relativistic formulations, while most variations of the Copenhagen Interpretation[4], Bohmian mechanics[5], objective collapse theories[6] (GRWf, GRWm, CSL), and MWI[7] and others[8] depend on the non-relativistic Schrödinger equation or Hilbert space representations**.**

Relativistic quantum field theories (QFT) typically assume flat Minkowski spacetime**,** bypassing GR's curved framework. Approaches to GR-QR, including Causal Dynamical Triangulations,[9] Asymptotic Safety in Quantum Gravity,[10] and the Holographic Principle,[11] focus on mathematical constructs without addressing the SR-QM tension.

String Theory[12] embeds SR and GR into higher-dimensional frameworks using Hilbert and Fock spaces to describe quantum states and interactions. However, it fails to address foundational challenges such as causality, locality, and the ontological basis of 4D spacetime. Loop Quantum Gravity (LQG)[13], in contrast, operates within a 4D spacetime framework and quantizes spacetime into discrete spin networks and spin foams. While more physically grounded, LQG struggles to reconcile probabilistic frameworks, physical observables, and the nature of time within 4D spacetime**.**

Sophisticated mathematical formulations across these theories often blur the line between physical ontology and abstract constructs**.** *Semi-ontological* approaches such as

[4] (Howard, 2004).
[5] (Dürr et al., 1995); (Goldstein & Zanghi, 2011).
[6] (Bassi & Ghirardi, 2003); (Bassi et al., 2012).
[7] (Deutsch, 1985); (Wallace, 2012); (Vaidman, 2021).
[8] (Allori, 2013, 2016); (Carroll, 2022); (Cramer, 1986); (Fuchs et al., 2014); (Griffiths, 2003); (Hubert & Romano, 2018); (Norsen et al., 2015); (Rovelli, 1996). For discussions on 3N ontic spaces, see (Albert, 2013); (Ney, 2021, 2023).
[9] (Ambjorn, et al., 2013).
[10] (Niedermaier & Reuter, 2006).
[11] (Hooft, 1993).
[12] (Danielsson, (2001).
[13] (Rovelli & Smolin, 1995).

GRWf, GRWm, CSL, and Multi-Field Theories treat mathematical structures as ontic components, complicating their reconciliation with GR and SR. Frameworks like MWI lack clear mechanisms to reconcile quantum phenomena with GR and SR, while models based on Hilbert space, Fock space, or 3N configuration spaces frequently lead to unphysical conclusions**.** For example, while 4D spacetime alone cannot fully explain the dynamics of N-body quantum states, many models represent these states as evolving within non-physical, ultra-high-dimensional spaces.

1.4. The DO Model

The DO model addresses the limitations of current theories by introducing a fully relativistic framework that integrates a discrete 4D spacetime and a physical, ultra-high dimensional *Planck Dimension*. The framework provides a unified, ontological, and dynamic model based on a single set of physical laws applied uniformly across scales and domains.

Section 2 introduces the DO's ontological framework, highlighting its discrete 4D spacetime structure and integration with a physical Planck Dimension. Sections 3 through 6 examine the relativistic dynamics of quantum states, focusing on the SR-QM tension, quantum path irreversibility, and the arrow of time. Section 7 explores the GR-QG tension. Section 8 explores the instantaneous transition of 4D spacetime from heat death to $t = 0$ and identifies the physical source of the cosmological constant. Section 9 serves as a Coda on the quantum-classical divide, and Section 10 provides concluding remarks. Appendix A contains the discrete mathematical formulations supporting the DO framework.[14]

2. The Ontological Framework of the DO Model

The DO model consists of two physical structures: a discrete 4D spacetime and an ultra-high dimensional Planck Dimension.[15] Both 4D spacetime and the Planck Dimension are composed of two ontological substructures: discrete spatial units referred to as Discrete Spheres and a State of Absolute Nothingness (SOAN). Discrete Spheres and the SOAN both play critical roles in the physical integration of 4D spacetime and the Planck Dimension, creating a tightly integrated, physical model.

2.1. Discrete Spheres

Under the DO model, Discrete Spheres are quantized, three-dimensional units of space that form the discrete substructure of both 4D spacetime and the ultra-high-

[14] For earlier versions of this analysis see (Kahan, 2024a, 2024b).
[15] For earlier discussions on high dimensional spaces see (Genovese, 2023); (Howard, 1989, pp. 247-253); (Monton, 2006).

dimensional Planck Dimension. Each Discrete Sphere is structurally invariant, possessing identical shape and volume, and represents the smallest structural quanta of space.[16] Each is identified by a unique set of x, y, z coordinates, and "N" designates the number of Discrete Spheres that comprise both domains.

The dual presence of each Discrete Sphere in both 4D spacetime and the Planck Dimension is referred to as the *Planck Identity,* which establishes a one-to-one identity and mapping between domains.[17] The mapping, facilitated by the SOAN (section 2.2), ensures that each Discrete Sphere occupies the same x, y, z coordinates in 4D spacetime and the Planck Dimension, creating a tightly integrated ontological framework.[18]

2.2. The SOAN

The concept of nothingness has long perplexed philosophers and scientists. Greek and Roman thinkers struggled with zero and the void. Although these concepts no longer trouble most physicists, "nothing" is now used figuratively to mean "not anything" rather than an ontic state of nonexistence. For example, in GR, "nothing," as in "not anything," describes what 4D spacetime expands into after its inception at $t = 0$. Consistent with this idea, "nothing" has also been used to denote the absence of *space* and *time*.[19] In LQG, the term "nothing" describes the interstices of discrete spin networks.[20]

Nevertheless, the concept of an ontic SOAN, devoid of *space* and *time,* remains alien to theoretical physics, partly because a physical nothingness cannot be experimentally verified. Rather than discarding the concept outright, this analysis focuses on its explanatory role. Under the DO model, the SOAN provides a physical explanation for the one-to-one link between each Discrete Sphere in 4D spacetime and the Planck Dimension, as well as the dynamic evolution and instantaneous collapse of quantum states.

The SOAN's only defining attribute is onticness; it lacks all other physical properties.[21] Since it excludes positive physical attributes, the SOAN is a passive ontological entity. It cannot be observed or measured, has no structure or boundaries, and is not governed

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[16] For illustrative purposes, Discrete Spheres have a volume of 2.2×10^{-105} meters.

[17] (Monton, 2002, 2006): (Ney, 2021); See also (Chen, 2017).

[18] For any given time t, the Planck Identity can be expressed as a bijective function f mapping from 4D spacetime R4 to the (3 x N) dimensional Planck Dimension R3×N: f: R4→R3×N. For a given set of coordinates (x,y,z,t), the function f maps these coordinates to $f((x,y,z,t)) = ((x1,y1,z1),(x2,y2,z2),\ldots,(xN,yN,zN))$ where 1) each tuple (xj,yj,zj)) represents a discrete 3-dimensional spatial point in the Planck Dimension, and 2) the Planck Dimension does not have an independent time parameter.

[19] Interview with Sean Carroll, Vice Magazine Online. "What is Nothing?" with Nick Rose, October 31, 2018.

[20] (Rovelli, 2017, p. 152).

[21] More specifically, the SOAN is devoid of space, time, dimension, boundary, size, structure, volume, gravity, energy, pressure, temperature, force, fields, ground states, vacuum states, virtual particles, quantum fluctuations, dynamic properties, frame of reference, matter, strings, information, mathematical entities, potentials, concepts, abstractions, consciousness, positive physical laws, possibilities, or entropy. See (Barrow, 2002); (Grünbaum, 2009); (Holt, 2012); (Leslie & Kuhn, 2013); (Moghri, 2020).

by the laws of physics. Consequently, explanatory depth, rather than experimental testing, is fundamental to the SOAN's role in the DO model. Viewed from an explanatory depth perspective, the SOAN is fundamental to the resolution of tensions between GR-QR and SR-QM and provides coherent explanations for long-standing cosmological issues.

2.3. Discrete 4D Spacetime

Unlike GR's conception of 4D spacetime as a continuous, differentiable manifold, the DO framework posits that 4D spacetime is composed of "N" Discrete Spheres.[22] The DO model retains the background independence and dynamics of 4D spacetime governed by the laws of GR and SR. Mathematically, the structure and dynamics of 4D spacetime remain consistent with the Einstein Field Equations in their discrete form; however, the DO model fundamentally redefines the ontological basis of 4D spacetime itself, providing a novel interpretation of its relationship to curvature, expansion, and the cosmological constant.

The DO model replaces the linear, non-relativistic Schrödinger equation, as well as Hilbert Space, Fock Space, and 3N configurations with a single set of physical laws including Maxwell, Dirac, and Klein-Gordon equations, a modified Regge Calculus for discrete spacetime, discrete Einstein field equations for a curved, discrete spacetime, and specific laws governing quantum state evolution and collapse.

2.4. The Planck Dimension

The Planck Dimension is the second core ontological structure in the DO model. Like discrete 4D spacetime, the Planck Dimension is composed of Discrete Spheres and the SOAN. Mathematically, the Planck Dimension is composed of N-tuples of ordered triples: $Q_n = \{(x_1,y_1,z_1), (x_2,y_2,z_2),...,(x_n,y_n,z_n)\}$where each N-tuple represents the three (x, y, z) spatial dimensions of a Discrete Sphere.

The Planck Dimension is composed of (3 x N) dimensions, where 3 represents the spatial dimensions of each Discrete Sphere, and N represents the number of Discrete Spheres.[23] The Planck Dimension fundamentally differs from 4D spacetime.[24] It has no time dimension,[25] physical properties of space, and no volume, and the laws of GR and SR, the strong nuclear force, the electro-weak force, or thermodynamics do not govern it. Moreover, unlike mathematical spaces composed of mutually orthogonal vectors, the Planck Dimension integrates N Discrete Spheres into a single *Planck Point*. For example, the 5.58×10^{186}

[22] Whether 4D spacetime is a continuous or discrete space is an unsettled subject. (Crouse, 2016); (Hagar, 2015); (Hossenfelder, 2013, 2014); (Smolin, 2004).
[23] See (Lewis, 2013, p. 116) for an early use of an ultra-high dimensional (3 x N) space.
[24] See generally (Banerjee et al, 2016).
[25] See generally (Adams, 2019, p. 158).

Discrete Spheres that comprise the observable portion of 4D spacetime form a single Planck Point composed of (3 x 5.58 x 10^{186}) dimensions.

2.5. The Tightly Integrated DO Model

The (3 x N) Planck Dimension and the 3 spatial dimensions of discrete 4D spacetime form the DO model's single, tightly integrated ((3 x N) + 3) physical structure. The Discrete Spheres that constitute both 4D spacetime and the Planck Dimension are linked by the SOAN, which serves as a non-spatial, non-temporal bridge between the two dimensions. Although the DO's ((3 x N) + 3) structure may initially appear complex, its core is much simpler. Based on an ontic SOAN, the DO framework links 4D spacetime and the Planck Dimension into a single physical structure, forming a unified framework that exists in the same location as 4D spacetime. More proverbially, 4D spacetime does not exist "here," and the Planck Dimension does not exist "there"; they co-exist in the same physical space.

Imagine, for example, that 4D spacetime consists of Discrete Spheres and that the SOAN exists within the interstices of these spheres. Assume there are five Discrete Spheres: one each on Venus, Mars, Jupiter, Sirius, and Polaris. In 4D spacetime, the Discrete Spheres are spatially separated, and each is represented by a set of x, y, z coordinates. However, since the SOAN, rather than space, exists in the interstices between Discrete Spheres, from the perspective of the Planck Dimension, these five spheres are not separated by time, space, or volume. The five Discrete Spheres form a single, unified 15-dimensional point (3 x 5) in the Planck Dimension, where 3 represents the three spatial dimensions of each sphere, and 5 represents the five spheres.

2.6. The Planck Identity and Quantum States

The significance of the Planck Identity's one-to-one identity and mapping extends beyond the physical integration of 4D spacetime and the Planck Dimension. First, the Planck Identity ensures that N-body quantum states, which cannot be fully described in 4D spacetime alone, are identified and mapped in both dimensions. Second, dynamic changes in the physical characteristics of quantum states as they evolve in 4D spacetime are mirrored in the Planck Dimension, and physical changes caused by the collapse of a quantum state in the Planck Dimension are mirrored in 4D spacetime.

3. The DO and the Dynamics of Quantum States

3.1. The Dynamic Evolution of Quantum States

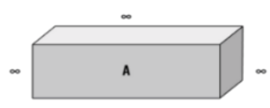
The analysis begins with the dynamic evolution of a single quantum state in a discrete 4D spacetime composed of Discrete Spheres and the SOAN. As a quantum state evolves in 4D spacetime, its energy occupies Discrete Spheres. The combination of a single Discrete

Sphere and the portion of the quantum state's energy within that sphere is referred to as a *Bell Sphere*. Building on the Planck Identity, the *Bell Identity* establishes a one-to-one identity and mapping between a Bell Sphere in 4D spacetime and the Planck Dimension.

In 4D spacetime, all of the Bell Spheres occupied by a quantum state constitute its *Bell Field*, while in the Planck Dimension, the same Bell Spheres form the quantum state's single, ultra-high-dimensional *Bell Point*. The quantum energy component of a given Bell Field in 4D spacetime is referred to as the *Bell Energy Field*, and the quantum energy component of a Bell Point in the Planck Dimension is referred to as the *Bell Energy Point*. For example, the 1.92×10^{74} Bell Spheres that comprise an electron in the ground state of hydrogen simultaneously form the electron's Bell Field in 4D spacetime, and its single ($3 \times 1.92 \times 10^{74}$)-dimensional Bell Point in the Planck Dimension.[26] As a quantum state spreads in 4D spacetime, the number of Bell Spheres it occupies increases. The Bell Identity ensures a corresponding increase in the number of Bell Spheres comprising the quantum state's Bell Point in the Planck Dimension.

3.2. The Collapse of a Single Quantum State

The Bell Identity also links the instantaneous collapse of a quantum state's Bell Energy Point in the Planck Dimension with the collapse of its Bell Energy Field in 4D spacetime. Following the collapse of a Bell Energy Point, the number of Bell Spheres that comprise the quantum state's Bell Point is reduced. Simultaneously, the Bell Identity ensures that the decrease in the number of Bell Spheres comprising the quantum state's new Bell Point is mirrored by a reduction in the number of Bell Spheres forming the quantum state's new Bell Field in 4D spacetime.[27] Discrete Spheres, themselves, do not collapse.



For example, assume that quantum state A is placed within impenetrable Box A with zero potential inside. Quantum state A forms Bell Field A in 4D spacetime and Bell Point A in the Planck Dimension. As quantum state A spreads, the Bell Identity ensures that the increase in the number of Bell Spheres comprising Bell Field A is mirrored by a corresponding increase in the number of Bell Spheres comprising Bell Point A. The opening of Box A triggers the instantaneous collapse of Bell Energy Point A, causing an

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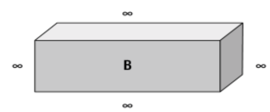
[26] For any given time t, the Bell Identity can be expressed as a bijective function g mapping from 4D spacetime R^4 to the (3 x N) dimensional Planck Dimension $R^{3\times N}$: $g: R^4 \rightarrow R^{3\times N}$. For a given set of Bell Sphere coordinates (x,y,z,t), the function g maps these coordinates to $g((x,y,z,t)) = ((x_1,y_1,z_1),(x_2,y_2,z_2),\ldots,(x_N,y_N,z_N))$ where 1) each tuple (x_j,y_j,z_j)) represents a discrete 3-dimensional spatial point in the Planck Dimension, and 2) the Planck Dimension does not have an independent time parameter.

[27] See Appendix A, sections 3.1 and 3.2.

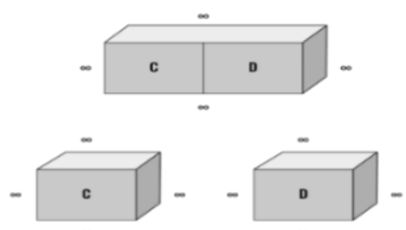
instantaneous reduction in the number of Bell Spheres that comprise Bell Point A. The Bell Identity ensures that the reduction is mirrored by an identical reduction in the number of Bell Spheres that contain Bell Energy Field A in 4D spacetime. Quantum state A is instantaneously generally localized within Box A, but SR has not been violated.

3.2.1. The Einstein/de Broglie Boxes Thought Experiment

The Einstein/de Broglie thought experiment[28] further illustrates the dynamic evolution of a quantum state. Quantum state B is generated, forming Bell Field B in 4D spacetime and Bell Point B in the Planck Dimension. The quantum state is inserted into Box B. As it spreads, it occupies an increasing number of Bell Spheres in 4D spacetime and the Planck Dimension.



An impenetrable divider is inserted into Box B, creating Box C and Box D. The quantum state now forms two equal Bell Fields in 4D spacetime, Bell Field C and Bell Field D, and a single Bell Point in the Planck Dimension, designated as Bell Point CD. Box C is sent to Princeton, and Box D is sent to Copenhagen.



Despite their separation, the Bell Identity ensures the quantum state continuously forms Bell Fields C and D in 4D spacetime and Bell Point CD in the Planck Dimension.

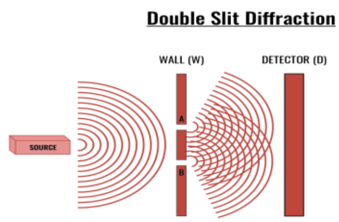
The opening of Box C or Box D triggers the collapse of Bell Energy Point CD, reducing the number of Bell Spheres that form the quantum state's new Bell Point. The reduction is mirrored in 4D spacetime. If the quantum state is found in Box C, the quantum state forms generally localized Bell Field C in Box C and Bell Point C in the Planck Dimension, while Bell Field D and Bell Point D cease to exist. Conversely, if the quantum state is found in Box D, the quantum state forms generally localized Bell Field D in Box D

[28] For detailed discussions see (Allori, 2022); (Bricmont, 2016); (Broglie, 1964); (Norsen, 2005).

and Bell Point D in the Planck Dimension, and Bell Field C and Bell Point C no longer exist. The process is the same regardless of which box is opened first.[29]

3.2.2. The Double-Slit Experiment

In the double-slit experiment, individual quantum states are directed at Wall (W), which has two narrow Gaussian slits (A) and (B). Due to the narrowness of the slits, every quantum state that passes through slit (A) or slit (B) diffracts. Some quantum states hit the wall, while others pass through the slits, spreading as spherical waves toward Detector D.



As a quantum state diffracts through slit (A) and slit (B), its Bell Field splits into two separate fields in 4D spacetime, Bell Field A and Bell Field B.[30] In the Planck Dimension, the fields remain unified as a single Bell Point AB. A detection flash at Detector D indicates that the Bell Energy Point AB has collapsed. The collapse reduces the number of Bell Spheres comprising the quantum state's Bell Energy Point in the Planck Dimension. The Bell Identity ensures that the reduction is mirrored in 4D spacetime, localizing the quantum state's Bell Energy Field to one of the diffracted paths. Following quantum collapse to either Bell Field A or Bell Field B, the other field ceases to exist. The interference pattern observed on Detector D arises cumulatively, reflecting the probabilistic outcomes of individual quantum collapses.[31]

3.2.3. A Which-Way Experiment

Which-way experiments compound the theoretical complexities of the double-slit experiment. The following which-way experiment has been modified by including a proton in an empty box at the center of Wall (W).[32] The proton is positively charged, and each electron fired toward Wall (W) is negatively charged. Slit (A) flashes if the proton is attracted toward slit (A), and slit (B) flashes if it is attracted toward slit (B).

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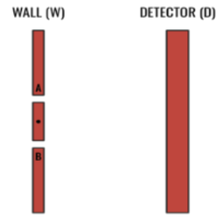
[29] See Appendix A, sections 3.2 and 4.2,
[30] A quantum state is often described by its wave function. Nevertheless, if an ontic quantum state passes through slits A and B, the charge density and the energy content of the quantum state must also do so. See generally (Sebens, 2021, 2023).
[31] The Bell Identity ensures unitarity. See (Gao, 2019). The DO model also resolves the tails problem in (McQueen, 2015).
[32] The which-way monitoring experiment is based upon the example presented in (Maudlin, 2019, pp. 14-16).

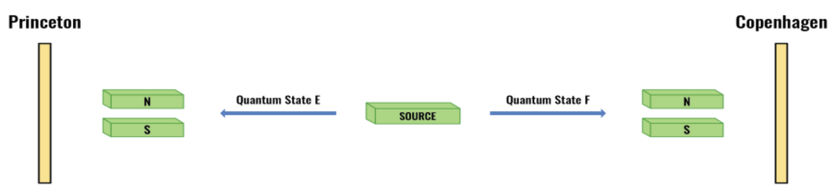


Under the DO model, as the quantum state spreads in 4D spacetime, it continuously forms a Bell Field in 4D spacetime and simultaneously forms a single Bell Point in the Planck Dimension. If slit (A) flashes, the Bell Energy Point instantly collapses, reducing the number of Bell Spheres that make up its new Bell Point and Bell Field. The quantum state is now localized at slit (A). The analysis is the same if slit (B) flashes rather than slit (A).

Once the quantum state is generally localized at either slit (A) or slit (B), it again spreads toward Detector (D). However, since the quantum state collapses at either slit (A) or slit (B), but not both, no interference pattern forms at Detector (D).

3.3. N-Body Quantum States and The Bohm-EPR Thought Experiment

The Bohm version of the EPR experiment highlights issues related to the dynamic evolution of an N-body quantum state in 4D spacetime and its collapse in the Planck Dimension.[33] A pair of electrons is prepared in the singlet state. The singlet state forms Bell Fields E and F in 4D spacetime and a single Bell Point EF in the Planck Dimension. Quantum state E is sent toward Princeton, and quantum state F is sent toward Copenhagen. Testing equipment is configured to conduct a z-axis Stern-Gerlach experiment on either Bell Field E or F.



As Bell Fields E and F dynamically spread in 4D spacetime, the number of Bell Spheres that comprise their respective Bell Fields increases, as does the number of Bell

[33] For any given time t, with respect to an N-body quantum state, the Bell Identity can be expressed as a bijective function h mapping from 4D spacetime R^4 to the (3 x N) dimensional Planck Dimension $R^{3\times N}$: h: $R^4 \longrightarrow R^{3\times N}$. For a given set of Bell Sphere coordinates (x_1,y_1,z_1,t), $(x_2,y_2,z_2,t),\ldots,(x_k,y_k,z_k,t)$, the function h maps these coordinates to $h((x_1,y_1,z_1,t), (x_2,y_2,z_2,t),\ldots, (x_k,y_k,z_k,t)) = ((x_1,y_1,z_1), (x_2,y_2,z_2),\ldots,(x_k,y_k,z_k))$ where 1) each tuple (x_j,y_j,z_j)) represents a discrete 3-dimensional spatial point in the Planck Dimension, and 2) the Planck Dimension does not have an independent time parameter. The bijective function, as applied to an N-body quantum state, is consistent with Einstein's view of objective physical reality and satisfies Einstein's bijective completeness criterion as set forth in (Norsen, 2005).

Spheres that comprise Bell Point EF.[34] The Stern-Gerlach experiment in the z-axis in either Princeton or Copenhagen triggers the collapse of Bell Energy Point EF. The collapse instantaneously reduces the number of Bell Spheres that formerly composed Bell Point EF, and the reduction is mirrored by Bell Field E and Bell Field F, respectively. Bell Point EF now forms two independent Bell Points designated as Bell Point E and Bell Point F. Bell Point E shares a one-to-one mapping and identity with Bell Field E, and Bell Point F shares a one-to-one identity and mapping with Bell Field F.

Following the instantaneous collapse, Bell Point E and Bell Point F form a product state rather than an entangled state $\psi_{1,2}((x_1,y_1,z_1)_1,(x_2,y_2,z_2)_2) \rightarrow \psi_1(x_1,y_1,z_1)_1 \otimes \psi_2(x_2,y_2,z_2)_2$, and Bell Energy Field E and Bell Energy Field F are generally localized. Whether quantum state E is found in the z spin-up or z spin-down axis, quantum state F's spin is the opposite. SR has not been violated.

4. Physical Implications of the DO Model

4.1. Indeterminacy

Indeterminacy typically means a quantum system has a determinable property without a specific determinate value.[35] In a singlet state along the z-axis, spin is a determinable property, with z spin-up and z spin-down as determinate values. When quantum states z_1 and z_2 form a singlet state $\psi = \frac{1}{\sqrt{2}} (\uparrow z_1 \downarrow z_2 - \downarrow z_1 \uparrow z_2)$, the Bell Identity ensures that the singlet state forms a single Bell Point in the Planck Dimension and two corresponding Bell Fields in 4D spacetime. The DO framework ensures the physically indeterminate status of the singlet state until the quantum state collapses. After the singlet state instantaneously collapses, the quantum state transitions to a product state, where the spins of z_1 and z_2 become determinate, represented by either $\psi \rightarrow \uparrow z1 \downarrow z2$ or $\psi \rightarrow \downarrow z1 \uparrow z2$. Each quantum state now forms a unique Bell Point associated with its respective localized Bell Field in 4D spacetime.

4.2. Quantum State Emergence and Annihilation

Quantum state emergence and annihilation challenge the non-relativistic Schrödinger equation's reliance on static quantum spaces with a fixed number of quantum states.[36] Relativistic quantum field theory (QFT) addresses these variations, but the DO model offers a unique solution, representing quantum states as physical entities in both 4D spacetime and the Planck Dimension.

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[34] See Appendix A, sections 3.3 and 3.4 as well as sections 4.3 and 4.4.
[35] (Lewis, 2016, pp. 72-107).
[36] For a detailed discussion, see (Ney, 2021).

Under the DO framework, the Bell Identity links the Bell Spheres that comprise a quantum state's Bell Field in 4D spacetime and its Bell Point in the Planck Dimension. During quantum annihilation, the collapse of a quantum state's Bell Energy Point transfers the quantum state's observables to another system, eliminating the original state's Bell Energy Point and Bell Energy Field. During quantum emergence, a quantum state forms a new Bell Field in 4D spacetime and a corresponding Bell Point in the Planck Dimension.

4.3. Physical Triggers

In the DO model, *Physical Interactions* in 4D spacetime arise from one or more of the traditional Fundamental Forces: electromagnetism, the strong nuclear force, the weak nuclear force, and gravitational spacetime warping. Consequently, the Fundamental Forces govern not only all quantum state motion in 4D spacetime but also all Physical Interactions between quantum states, including all physical triggers that initiate the collapse of a quantum system in the Planck Dimension.

The DO model does not identify a precise Physical Interaction that induces quantum state collapse. Nevertheless, it offers a structured framework to investigate how these physical triggers may initiate collapse. Within the DO framework, each Physical Interaction is an independent event localized in time and space, with its frequency influenced by factors such as temperature and spatial positioning.[37] Local temperature and position within the Sun affect the rate of quantum state collapse. Humans can initiate or influence the timing and location of Physical Interactions.[38] However, Physical Interactions are independent of human consciousness, ambient noise, universal processes, or probability-based rules.[39]

4.4. Quantum State Localization

The Bell Identity links the collapse of a quantum state's Bell Energy Point to a simultaneous reduction in the number of Bell Spheres that comprise its Bell Energy Field in 4D spacetime. Since the reduction must be to a subset of the Bell Spheres that comprised the quantum state prior to collapse, the Bell Identity places a strict boundary on the collapse outcome. Following the collapse of a Bell Energy Point, a quantum state's new Bell Energy Field cannot be generally localized anywhere in the universe. It must be generally localized to a subset of its Bell Spheres prior to collapse, yielding a discrete spatial configuration consistent with observed quantum measurements.

[37] See generally (Licata & Chiatti, 2019).
[38] Humans can control and precisely vary the collapse rate of electrons using a scanning tunneling microscope.
[39] See generally (Bassi & Ulbricht, 2014); (Ghirardi, 2004, p. 406).

The Bell Identity does not set a specific size for a quantum state's Bell Field in 4D spacetime following collapse. The size of the Bell Field may be related to the physical trigger that initiated collapse or may vary based on the physical composition of the quantum state. In addition, high or low-energy collapses may have different localization characteristics, and a quantum state's momentum in 4D spacetime may also affect its localization.

4.5. Time and Instantaneous Collapse

Neither the Planck Dimension nor 4D spacetime independently supports the concept of instantaneous collapse. The Planck Dimension lacks a time dimension and, aside from collapse, does not support dynamic movement. In contrast, 4D spacetime has dynamic movement and a time dimension constrained by SR.

When a Physical Interaction in 4D spacetime occurs, the trigger is mirrored in the Planck Dimension, causing the quantum state's Bell Energy Point to collapse instantly. The Bell Identity ensures that the collapse is mirrored by a reduction in the number of Bell Spheres that comprise the quantum state's Bell Energy Field in 4D spacetime. Since the collapse of a Bell Energy Point is instantaneous, it is mirrored in the three spatial dimensions of 4D spacetime, with no movement along the time dimension.

4.6. Quantum Tunneling

Though commonly described as 'quantum tunneling,' the appearance of a quantum state on the opposite side of a classically impenetrable barrier does not involve quantum tunneling in 4D spacetime. In many traditional interpretations, the probability of a quantum state appearing on the other side of an impenetrable barrier is based on the Schrödinger equation and the exponential decay of the quantum state's wave function within the barrier.

Under the DO model, the event is not tunneling but rather the instantaneous collapse of the quantum state's Bell Energy Point in the Planck Dimension. When a quantum state's Bell Energy Point undergoes instantaneous reduction, the Bell Identity ensures a corresponding reduction in the number of Bell Spheres that constitute the quantum state's new Bell Energy Field in 4D spacetime. Although the quantum state is localized on the other side of the barrier, it does not "tunnel" through, and SR is not violated.[40]

4.7. The Born Rule Revisited

The DO model diverges fundamentally from the Born Rule and its probability density interpretation of wave-function collapse for continuous variables. Unlike the Born Rule, the

[40] See generally (Allori et al., 2021).

DO model asserts that a quantum state cannot appear instantaneously anywhere in 4D spacetime following its collapse. Instead, collapse is restricted to a discrete subset of the Bell Spheres occupied by the quantum state prior to collapse.[41]

Accordingly, rather than integrating a density function of the quantum state over a continuous space, the likelihood of generally locating a quantum state in a discrete, constrained space is determined by the square modulus of the quantum state's wave function.[42] For example, in the case of quantum tunneling, the collapse of a quantum state on the opposite side of a classically impenetrable barrier is a probability event, not a probability density.[43] [44]

5. Resolving the Tension Between SR and Quantum Mechanics

The apparent incompatibility between SR and QM is often framed by terms and concepts derived from 4D spacetime. Despite their usefulness, common terms such as space-like separated, non-separability, entangled, instantaneous, local, non-local, as well as complex concepts like the relativity of simultaneity and relativistic energy increase, have unintentionally magnified a theoretical and experimental conflict that does not exist.

5.1. Space-Like Separated

The term space-like separated is based upon a 4D spacetime structure composed of three dimensions of space and one dimension of time. The term is directly related to the concepts of space and time, the theory of SR, and the spatial distance between two or more events outside of one another's light cones. Nevertheless, the term loses meaning in relation to an ultra-high dimensional Bell Point where time, space, and volume do not exist.

5.2. Non-separability

Einstein was among the first to raise concerns regarding separability in theoretical physics. His primary concern related to two assumptions underlying his argument for incompleteness: that spatially separated systems are ontic states and that physical effects in space-like separated systems cannot propagate faster than light.[45] [46]

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[41] See (Bacciagaluppi & Valentini, 2009, p. 136) regarding Schrödinger and Born debates on the probability density rule.

[42] Under the DO model, the probability of finding the location of a quantum state in a generalized location is one.

[43] The Bell Identity ensures unitarity throughout quantum state evolution in 4D spacetime and collapse in the Planck Dimension. See (Gao, 2019). Moreover, the DO framework resolves the tails problem. See (McQueen, 2015).

[44] The DO framework leaves unanswered whether QM is fully deterministic. See (Hossenfelder & Palmer, 2020).

[45] Einstein's primary concern was not with non-separability per se but with the possibility that non-separability implied a violation of special relativity. (Howard, 1985, pp. 172-173); (Howard, 1989, p. 232). See also (Maudlin, 2011, pp. 88-89).

[46] Einstein also questioned whether spatially separated quantum states in 4D spacetime had an independent reality. (Wiseman, 2006).

In 4D spacetime, a singlet state along the z-axis $\psi = \frac{1}{\sqrt{2}} (\uparrow z_1 \downarrow z_2 - \downarrow z_1 \uparrow z_2)$ is non-separable, although it is often considered an abstract mathematical concept. A non-separable singlet state has three key attributes: 1) spatial separation of the z_1 and z_2 states, 2) temporal separation of the z_1 and z_2 states, and 3) the existence of a single system.

In the Planck Dimension, without time, space, or volume, a Bell Point exists as a single, non-separable entity.[47] The Bell Point is mirrored via the Bell Identity to the Bell Spheres that form the quantum state's Bell Field(s) in 4D spacetime. The non-separability of a Bell Point in the Planck Dimension does not violate SR.

5.3. Instantaneous, Superluminal, and Faster than Light

In QM, the terms *instantaneous, superluminal*, and *faster than light* often describe the collapse of a quantum state in 4D spacetime. Following quantum state collapse, the terms are used to describe the quantum state's role in 1) communication, 2) signaling or the absence of signaling, 3) information transmission, and 4) matter and energy transfer.

Under the DO model, however, terms such as *instantaneous* describe the physical collapse of a Bell Energy Point in the Planck Dimension rather than a collapse in 4D spacetime. Following the collapse, the reduction in the number of Bell Spheres that comprise a quantum state's new Bell Point in the Planck Dimension is mirrored by a reduction in the Bell Spheres that comprise the quantum state's generally localized Bell Field in 4D spacetime. The process is instantaneous, but SR is not violated.

5.4. The Quantum Connection

In 4D spacetime, quantum discrimination describes a quantum state's ability to maintain an exclusive connection to the exclusion of all other quantum states, and unattenuated denotes the strength (or non-attenuation) of a quantum state's connection.[48] The terms are typically used to denote the connection between space-like separated entangled states. Discrimination and non-attenuation also imply an instantaneous and continuous connection that violates the maximum speed of light.

In the DO model, the Bell Identity ensures that all dynamic changes to Bell Spheres are mirrored in both 4D spacetime and the Planck Dimension. The mirroring process ensures quantum discrimination and non-attenuation without violating SR.

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[47] See (Ney, 2016, 2021).
[48] See (Maudlin, 2011, pp. 21-2).

5.5. Bell's Theorem, Locality, Non-locality, and Quantum Collapse

John Bell's inequality theorem asserts that relativistic local causation theories cannot account for the statistical predictions of quantum mechanics in spin experiments of entangled states in the singlet state.[49] More broadly, Bell's theorem indicates that any theory conforming to quantum experimental results cannot be local.[50]

Nevertheless, the DO model shifts Bell Energy Point collapse to the Planck Dimension, where time and space do not apply, and the typical notion of non-local collapse is not relevant. Despite the shift, the DO framework strengthens Bell's theorem. Rather than invoking a problematic non-local event, the collapse of a Bell Energy Point and the generalized localization of a quantum state in 4D spacetime bypass the non-locality issue.

5.6. The Relativity of Simultaneity

The SR and QM tension extends to the relativity of simultaneity. SR holds that 1) all inertial reference frames (frames moving at constant speed relative to one another) are equally valid, and 2) the speed of light in a vacuum is invariant for all observers in these frames. Consequently, the relativity of simultaneity implies that a) whether two spatially separated events occur simultaneously depends on the observer's frame of reference, and b) observers in different frames may conclude that the same event happened at different times.

For space-like separated electrons in the singlet state in the z-axis $\psi = \frac{1}{\sqrt{2}} (\uparrow z_1 \downarrow z_2 - \downarrow z_1 \uparrow z_2)$, collapsing the z_1 electron causes the simultaneous collapse of the z_2 electron. Since relativity of simultaneity suggests that the order of cause (collapse of z_1) and effect (collapse of z_2) depends on the observer's frame of reference, the simultaneous collapse appears to challenge SR, implying a violation of Lorentz Invariance and a preferred frame.[51]

The DO model resolves the issue by treating quantum state collapse as an event beyond 4D spacetime. For a singlet state in the z-axis, it is irrelevant whether z_1 or z_2 is measured first or whether they are space-like separated. The Bell Identity ensures that an experiment on either quantum state in 4D spacetime is simultaneously conducted on the quantum state's single Bell Point in the Planck Dimension. Moreover, the identity reflects the instantaneous collapse of the Bell Energy Point as a reduction in the Bell Spheres comprising the now generally localized Bell Energy Fields of both z_1 and z_2 in 4D spacetime. The formerly entangled quantum state becomes a product state, and although the collapse was instantaneous, SR remains intact.

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[49] (Goldstein et al., 2011); (Maudlin, 2014, p. 21); See also (Bell & Gao, 2016).
[50] (Brunner et al., 2014); (Norsen, 2011).
[51] (Maudlin, 2011, p. 185).

5.7. Relativistic Energy Increase

The instantaneous nature of quantum state collapse appears to challenge Einstein's relativistic energy increase theory. The theory posits that the relativistic energy of a body moving relative to an observer increases as its velocity accelerates. As an object approaches the speed of light, its relativistic kinetic energy theoretically approaches infinity, though SR limits its speed. In quantum mechanics, momentum is typically used instead of velocity; accordingly, as a quantum state's momentum increases, so does its associated energy. To reach or exceed the speed of light, as in the case of instantaneous collapse, the energy required would be infinite.

While the collapse of a quantum state's Bell Energy Point is instantaneous, it is a physical event external to 4D spacetime. The DO model and the Bell Identity ensure that the instantaneous collapse results in a reduction in the number of Bell Spheres comprising the quantum state's Bell Point and Bell Field(s). Consequently, the reduction in Bell Spheres in the Bell Field is also instantaneous. However, the process does not result in a relativistic energy increase of the quantum state in either 4D spacetime or the Planck Dimension.

6. Quantum Path Irreversibility and The Arrow of Time

The Bohm version of the EPR experiment demonstrates why quantum path irreversibility is impossible.[52] Assume two quantum states, z_1 and z_2, are entangled in the singlet state in the z-direction $\psi = \frac{1}{\sqrt{2}}(\uparrow z_1 \downarrow z_2 - \downarrow z_1 \uparrow z_2)$. The Bell Field of z_1 is on Mars, and the Bell Field of z_2 is on Earth. The entangled state is separated by 225 million kilometers, and its spin is indeterminate. In the Planck Dimension, the singlet state forms Bell Point z_1z_2.

Following the instantaneous collapse of Bell Point z_1z_2, the z_1 and the z_2 form a product state $\psi_{1,2}((x_1,y_1,z_1)_1,(x_2,y_2,z_2)_2) \rightarrow \psi_1(x_1,y_1,z_1)_1 \otimes \psi_2(x_2,y_2,z_2)_2$ rather than an entangled singlet state. The Bell Identity ensures that the reduction in the number of Bell Spheres comprising Bell Point z_1z_2 is linked to the simultaneous reduction in Bell Spheres that comprise Bell Fields z_1 and z_2 in 4D spacetime. Bell Field z_1 is generally localized on Mars, and Bell Field z_2 is generally localized on Earth. The z_1 and the z_2 quantum states are now separable and form Bell Point z_1 and Bell Point z_2, respectively. If z_1 is spin-up, then z_2 is spin-down, and vice versa. The spin of the respective quantum states is now determinate.

Before quantum state collapse, 1) z_1 is on Mars, z_2 is on Earth, and z_1 and z_2 are separated by 225 million kilometers, 2) the singlet state forms Bell Point z_1z_2 in the Planck Dimension, 3) the singlet state is non-separable and its spin is indeterminate. Following the instantaneous collapse of Bell Energy Point z_1z_2, 1) z_1 is generally localized on Mars, z_2 is

[52] See generally (Albert D. Z., 2000, pp. 150-162); (Bahrami et al., 2015); (Doyle, 2014); (Price, 2004).

generally localized on Earth, and z_1 and z_2 remain separated by 225,000,000 kilometers, 2) the formerly entangled singlet state is now a product state, 3) z_1 forms Bell Field z_1 on Mars and Bell Point z_1 in the Planck Dimension, 4) z_2 forms Bell Field z_2 on Earth and Bell Point z_2, in the Planck Dimension 5) the product state is now separable, and 6) the spins of quantum states z_1 and z_2 are determinate even if they are unknown.

Since path reversibility must occur along the identical collapse path initially taken by the singlet state, path reversibility is physically impossible. Following the collapse of Bell Energy Point z_1z_2 in the Planck Dimension, Bell Point z_1z_2 no longer exists. Z_1 now forms Bell Field z_1 on Mars and Bell Point z_1 in the Planck Dimension, and z_2 now forms Bell Field z_2 on Earth and Bell Point z_2 in the Planck Dimension. Since Bell Field z_1 and Bell Field z_2 are now generally located on Mars and Earth, respectively, each quantum state must travel at least 112,500,000 miles before it can become entangled again. Even if there is an infinitely small chance that the z_1 and z_2 quantum states will spread and once again form Bell Point z_1z_2, at the moment the singlet state collapses, path reversibility becomes an impossibility.

The DO's ontological structure and the asymmetric laws governing the dynamic motion of quantum states in 4D spacetime and collapse in the Planck Dimension are the physical basis for 4D spacetime's arrow of time. Without an instantaneously reversible path, the arrow of time for all quantum states and those of the proverbial egg can only move in a single temporal and spatial direction.

7. GR, QM, and the Quantization of Gravity

7.1. Discretization, Singularities, and Regularization

The DO model replaces GR's assumption of a continuous, differential 4D spacetime manifold with a discrete 4D spacetime composed of Discrete Spheres. Critically, in the context of GR-QR, the physical discretization of 4D spacetime resolves several of the mathematical difficulties encountered by the Einstein Field Equations (EFE), including cosmological singularities, black hole singularities, and Regularization.

7.1.1. Cosmological and Black Hole Singularities

Specific mathematical solutions to the Einstein Field Equations (EFE), including the FLRW model, predict a cosmological singularity at $t = 0$, where density, pressure, and energy density become infinite. Similarly, the Schwarzschild solution to the EFE, based on a spherically symmetric, uncharged, and non-rotating mass, mathematically defines the conditions under which a curvature singularity forms at the center of black holes. In both cases, the EFE's lack of a physical mechanism to impose a cut-off at some minimum volume leads mathematically to infinite energy, mass, and pressure.[53]

Notwithstanding significant differences between cosmological and black hole singularities, discretization based on the minimum discrete size of Discrete Spheres provides a minimum volume cutoff that resolves the infinities in both cases. The discretization sets limits on the maximum possible frequencies and wavelengths for energy, creating a physical upper bound on energy density.[54]

7.2. Regularization

In QFT, summing the zero-point energy of quantum states across 4D spacetime leads to energy densities that approach infinity. Even with renormalization, the predicted energy density from quantum fluctuations can exceed the experimentally observed density by as much as 10^{120} times. The DO model resolves this by introducing Discrete Spheres, which act as a physical cutoff for the ultra-high energy modes. The cutoff prevents ultraviolet energy densities from diverging, yielding physical energy densities that are far below the mathematical prediction of zero-point energy summation.

7.3. Background Independence

Unlike the fixed background of flat Minkowski spacetime, the DO model introduces a discrete, background-independent 4D spacetime based on a tightly integrated ((3 x N) + 3) framework. Single and N-body quantum states evolve dynamically under novel laws of quantum state evolution and collapse, fully consistent with SR.[55] Quantum states form Bell Fields in 4D spacetime composed of discrete Bell Spheres, and changes in their mass, energy, and pressure dynamically shape the curvature of 4D spacetime. The interaction, governed by a discrete version of the EFE, ensures that spacetime geometry arises directly from the interaction of Bell Spheres.[56]

7.4. Time

In QFT's Hamiltonian and path integral formalisms (and the explicitly non-relativistic Schrödinger equation), time typically remains an external, fixed-parameter. Most QFT theories assume flat Minkowski spacetime, with time as an absolute Newtonian construct. In contrast, GR treats time as a dimension within 4D spacetime, where the rate at which time

[53] See (Curiel, 2023).
[54] Discreteness suppresses but does not eliminate the high energy scale associated with very small volumes.
[55] See Appendix A, sections 3 and 4.
[56] See section 8. The DO framework extends to the discrete mathematical formulations of the electromagnetic, electroweak, and strong nuclear forces in Appendix A, Sections 1 and 2. See generally (Smolin, 2005).

passes depends on local mass, energy, and pressure, as reflected in spacetime's curvature. Time dilation, gravitational redshift, and lensing reflect its relative nature.

The DO model's approach to time diverges from both perspectives by integrating the Planck Dimension, which lacks a time dimension. Except for quantum collapse, the Planck Dimension has no independent dynamic movement. Single and N-body quantum states evolve entirely within 4D spacetime, governed by the laws of GR and SR. As a result, quantum state dynamics follow SR constraints, including the maximum speed of light, time dilation, relativistic energy increase, and the EFE, reflecting the influence of gravity on spacetime curvature. While Discrete Spheres set the smallest unit of time at approximately the Planck length, time remains a dynamic concept shaped by GR and SR rather than QM.

7.5. Non-locality, Entanglement, Instantaneity and Quantizability

Within a closed 4D spacetime framework, attempts to quantize gravity have failed. The EFEs treat gravity as inherently local, governed by SR, but quantum entanglement is often regarded as a non-local phenomenon with instantaneous changes to an N-body quantum state's wave function.[57] [58] Since gravitons must adhere to SR, instantaneous changes in location and momentum would violate gravity's locality.[59] Additionally, because QM holds that the position of a quantum state is undefined before collapse, it is unclear whether gravity couples to an N-body quantum state's aggregate or each constituent quantum state.

Instantaneous collapse also appears to violate Einstein's theories of simultaneity and relativistic energy increase.[60] Many QM interpretations represent the collapse with a Dirac delta function $\delta(x-x0)$, implying infinite localization, infinite momentum uncertainty, and potential black hole formation.[61]

Under the DO model, however, all quantum states evolve in a discrete, SR-compliant 4D spacetime. Bell Energy Points collapse instantly in the Planck Dimension, where 4D spacetime's laws do not apply. The collapse of a Bell Energy Point localizes the quantum state in 4D spacetime rather than collapsing to a delta function.

Since the Bell Identity links each quantum state's Bell Spheres across both domains, changes in energy, mass, pressure, or sphere count are mirrored instantaneously. The mirroring underscores the difference between quantum observables tied to Bell Points and the purely relational nature of gravity in 4D spacetime, explaining why the electromagnetic, weak, and strong forces are quantizable, but gravity is not. A quantum state's Bell Spheres form its Bell Field(s) in 4D spacetime and its single Bell Point in the Planck Dimension. Bell

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[57] See generally (Oppenheim, 2023).
[58] (Maudlin, 2011).
[59] Gravitons do not exist in the DO model.
[60] See sections 5.6 and 5.7 above.
[61] (Norsen, 2017).

Spheres hold all the information (spin, momentum, position) of the N-body quantum state in both domains. Gravity, however, does *not* arise from intrinsic Bell Sphere properties. It emerges relationally among Bell Spheres in 4D spacetime, governed by the EFEs coupling mass, energy, and pressure to curvature. Accordingly, gravitational effects remain independent of entangled quantum states or quantum observables.

While quantum observables depend on a quantum state's intrinsic properties, gravity emerges classically from relational configurations in 4D spacetime. Gravity cannot be quantized under the DO approach, nor can an N-body state's energy-momentum tensor approximate its gravitational influence.[62] Since there is no known method to pinpoint a quantum state's Bell Spheres at any moment in time, their gravitational effects can only be approximated, limiting precision in modeling quantum-gravitational interactions."[63]

7.6. The Black Hole Information Paradox

The black hole paradox is based on the apparent conflict between two principles: 1) the QM principle that information is never lost, and 2) Stephen Hawking's 1975 semi-classical premise that information falling into a black hole is eventually lost through Hawking radiation. The QM principle relates closely to unitarity and the reversibility of quantum processes. Hawking's key premise is that a black hole loses mass and energy through the emission of thermal radiation at its event horizon. Since the quantum state of matter falling into the black hole is inaccessible beyond the event horizon, and thermal radiation is presumed to carry no specific information, the process implies that the information is permanently lost.[64]

Under the DO framework, when a quantum state's Bell Field(s) falls into a black hole, the quantum state and its information are no longer accessible in 4D spacetime. However, as long as the quantum state does not collapse, it is still represented by its Bell Field(s) within the black hole and by its single Bell Point in the Planck Dimension. As the quantum state dynamically evolves within the black hole, any changes to the content or number of Bell Spheres in the Bell Field are instantaneously mirrored by its Bell Point.

The transition to thermal radiation, triggered by a physical interaction inside the black hole, causes the instantaneous collapse of the quantum state's Bell Energy Point. In 4D spacetime, the collapse causes the quantum state's transition to radiation via the Hawking process. Although this collapse is irreversible, the Bell Point allows for the theoretical identification of the quantum state that transitions to thermal radiation. While detailed

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[62] See (Bedingham, 2021).

[63] Spacetime's curvature at any given point according to the EFE is given by $G_{\mu\nu} = 8\pi T_{\mu\nu} - \Lambda g_{\mu\nu}$.

[64] The DO's ontological and dynamic framework challenges the no-hair theorem, which holds that thermal radiation only conveys information about electric charge, angular momentum, and total mass. See generally (Barceló et al., 2019).

information about the quantum state is not preserved, the DO model demonstrates that the quantum state's identity is not fundamentally lost.

8. Quantum Cosmology, Cosmogony, and the Cosmological Constant

The DO model departs significantly from current cosmological theories regarding 4D spacetime. Yet, it does not require ad hoc assumptions, fine-tuning, or perturbative techniques to explain the instantaneous collapse process that transforms a widely dispersed 4D spacetime at or near Heat Death to a generally localized 4D spacetime at $t = 0$. The collapse explains 4D spacetime's extreme but not infinite energy, pressure, and temperature at $t = 0$, its nearly isotropic and homogeneous status, as well as its extremely low gravitational entropy. The framework also provides a unified physical account of the horizon and flatness problems while clarifying the origin of the Λ independently of Dark Energy.[65]

8.1. The FLRW Model of 4D Spacetime at Heat Death

Cosmologically, 4D spacetime's status as open, closed, or flat is based upon the FLRW derivation of the EFE.[66] Experimental data currently suggests that k = 0, indicating that the universe is flat or very nearly flat. In turn, flatness implies that 4D spacetime's total energy density equals the critical density ($\rho = \rho_c$).[67] Based on the FLRW model and other datasets, at Heat Death, 4D spacetime is in a state of near-maximal entropy, and 4D spacetime's energy density, pressure, and temperature asymptotically approach zero.

At Heat Death, 4D spacetime's spatial geometry, energy density, pressure, and temperature are very nearly homogeneous and isotropic, and, as a result, 4D spacetime is very close to thermodynamic equilibrium. 4D spacetime has no large-scale structures, is extremely widely dispersed, and its spatial curvature is flat or nearly flat. Even though the negative pressure of Λ dominates, 4D spacetime's energy density equals the critical density $\rho = \rho_c$. Since little heat can flow near a thermal equilibrium approaching zero, little work or gravitational clumping can occur. At the macrostate level, no additional physical changes occur without work, and in the absence of work, 4D spacetime is in a state of near-maximal gravitational entropy.[68]

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[65] See generally (Bojowald, 2015).

[66] The EFE $is\ G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$. At Heat Death the equation simplifies to: $G\mu\nu + \Lambda g\mu\nu = 0$.

[67] 4D spacetime's total energy budget under the Friedmann equation is $\Omega_{\text{total}} = \Omega_\Lambda + \Omega_m + \Omega_r + \Omega_k = 1$.

[68] Changes may still occur at the microstate level.

8.2. The FLRW Model of 4D Spacetime at *t* = 0

Mathematical attempts to describe 4D spacetime at $t = 0$ support different conclusions regarding its physical status. Under specific conditions, the EFE and Friedmann equations describe a singularity at $t = 0$ caused by the divergence of energy density, pressure, and spacetime curvature. Specific modifications to the Friedmann equations allow the FLRW model to describe a homogeneous and isotropic 4D spacetime at very large scales, where the behavior of matter, radiation, and the cosmological constant govern its dynamics.

The ΛCDM model, based on the FLRW metric, does not describe 4D spacetime's physical status at $t = 0$. Nevertheless, based upon a continuous, differentiable 4D spacetime framework, the ΛCDM model, supported by experimental data from the CMB and other datasets,[69] indirectly indicates that approximately 13.8 billion years ago, immediately after $t = 0$, 4D spacetime was in a hot, dense state characterized by extreme energy densities, pressures, and temperatures.[70]

Approximately 380,000 years after $t = 0$, the temperature anisotropies of the CMB across the sky varied by approximately 1 part in 10^5. The temperature variations indirectly suggest that very near $t = 0$ 4D spacetime's energy density and pressure were nearly isotropic and homogeneous and contained very small anisotropies and inhomogeneities. When the angular power spectrum around the first peak of the anisotropies is extrapolated backward to $t = 0$, the CMB and related data indirectly support a 4D curvature that is nearly flat.[71]

8.3. The DO Model

8.3.1. 4D Spacetime

Under the DO framework, discretization resolves the infinities created by the EFE's continuous differentiable 4D spacetime manifold by creating an upper bound on the maximum possible frequencies and wavelengths for energy. Consequently, under the model, at $t = 0$, 4D spacetime is characterized by a discrete, generally localized 4D spacetime with extreme, rather than infinite, energy densities, pressures, and temperatures.

Although the metric expansion of 4D spacetime, described by the scale factor $a(t)$, colloquially represents an "internal stretching" of 4D spacetime rather than a stretching into *nothing*, the DO model posits that 4D spacetime expands into a pre-existing substructure comprised of Discrete Spheres and the SOAN.[72]

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[69] Including Type Ia Supernovae Observations, Hubble's Law and Redshift Observations, Baryon Acoustic Oscillations, Galaxy Redshift Surveys, Stellar Evolution Models, and Globular Cluster Age Estimates.
[70](Aghanim, 2021). See generally (Davies, 1994).
[71] See (Ijjas et al., 2013).
[72] The energy density of Discrete Spheres only become relevant when matter interacts with the spheres.

As we will see in Sections 8.4 and 8.7 below, this distinction provides a physical basis for a uniform cosmological constant (Λ) derived from the inherent energy density per unit volume of evenly distributed, pre-existing Discrete Spheres $\rho_{DS} = \rho_{\Lambda}$. Moreover, the existence of a pre-existing substructure space represented by Discrete Spheres 1) explains the physical source of Λ, 2) resolves the increasing total energy budget of 4D spacetime as it expands over time,[73] and 3) obviates the need for Dark Energy based on a vacuum energy density that exceeds the observed Λ by a factor of 10^{120}.

8.3.2. The Planck Dimension

In contrast to 4D spacetime, the Planck Dimension does not have a time dimension, lacks the physical properties of space and volume, and the physical laws of 4D spacetime do not apply to it. Aside from a collapse mechanism, the Planck Dimension does not support dynamic movement. Nevertheless, the Bell Identity ensures that the physical characteristics of the individual Bell Spheres occupied by quantum states in 4D spacetime, including the energy densities, pressures, and temperatures of individual Bell Spheres from $t = 0$ to Heat Death, are continuously mirrored in the Planck Dimension. Critically, since the Bell Spheres that comprise 4D spacetime's energy density, pressure, and temperature at Heat Death are very nearly homogeneous and isotropic, so too were the Bell Spheres that comprise the Planck Dimension.

In addition, the Planck Identity's mirroring effect ensures that 1) the total energy of 4D spacetime equals the total energy of the Planck Dimension and 2) 4D spacetime's total energy density per Discrete Sphere (ρ) at any instant in time, including $t = 0$ and Heat Death, equals the Planck Dimension's total energy density per Discrete Sphere (ρ_{pd}) ($\rho = \rho_{pd}$). Since 4D spacetime's total energy density equals the critical density at $t = 0$ and at Heat Death ($\rho = \rho_c$), the Planck Dimension's total energy density at $t = 0$ and Heat Death also equals the critical density ($\rho_{pd} = \rho_c$). Finally, since the quantized energy of the quantum states that comprise the Planck Dimension (the *Universal Bell Energy Point*) and 4D spacetime (the *Universal Bell Energy Field*) are identical, their total energy density budgets (Ω_{QS}) are also identical.

8.4. Heat Death and the Collapse of the Universal Bell Energy Point

The instantaneous collapse process that applies to all quantum states also applies to the Universal Bell Energy Point at Heat Death. Although the physical event that triggers the collapse of the Universal Bell Energy Point is unknown, it is based on a Physical Interaction in 4D spacetime.

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[73] See (Melia, 2023) regarding the cosmological principle and the constant expansion rate of 4D spacetime

The significance of the Universal Bell Energy Point's collapse cannot be overstated. The Bell Identity ensures that the collapse is mirrored by the generalized localization of 4D spacetime's Universal Bell Energy Field at $t = 0$.[74] Although the precise size of generalized localization is unknown, since the Universal Bell Energy Point was homogeneous and isotropic at heat death, the Bell Identity ensures the 4D spacetime also remains homogeneous and isotropic at $t = 0$.

The instantaneous transition from Heat Death to $t = 0$ radically alters 4D spacetime's energy density, pressure, and temperature. At Heat Death, 4D spacetime's energy density, pressure, and temperature asymptotically approach zero. At $t = 0$, however, the generalized localization of the Universal Bell Energy Field causes an instantaneous and exponential increase in energy density, pressure, and temperature. Despite the extreme conditions of 4D spacetime at $t = 0$, the CMB indirectly confirms that the energy density, pressure, and temperature of the Universal Bell Energy Field at $t = 0$ continue to exhibit the near homogeneous and isotropic conditions of 4D spacetime at Heat Death.

The collapse of the Universal Bell Energy Point at or near Heat Death also explains 4D spacetime's instantaneous transition from a state of near maximal gravitational entropy at Heat Death to near-zero gravitational entropy at $t = 0$. At Heat Death, as energy density, pressure, and temperature asymptotically approach zero, no additional work occurs at the macrostate level, notwithstanding the continuing expansion and the presence of anisotropies and inhomogeneities However, following the collapse of the Universal Bell Energy Point and the generalized localization of the Universal 4D Field, the extreme energy density, pressure, and temperature, along with future expansion, reset 4D spacetime's gravitational entropy to near zero. Finally, neither Bell Spheres, in particular, nor Discrete Spheres, in general, collapse during the transition from Heat Death to $t = 0$. Their shape, size, intrinsic energy density, and total energy budget remain invariant, forming the stable, underlying fabric of both 4D spacetime and the Planck Dimension.

8.5. The Horizon Problem and Causality

The inability to explain 4D spacetime's exceptionally high homogeneity and isotropy at $t = 0$ is the source of the horizon problem. Given a singularity premised on an infinite density, pressure, curvature, and temperature and the constraints of the speed of light c, space-like separated regions of 4D spacetime following $t = 0$ could not have been in causal contact.[75] The problem is exacerbated by data from the CMB, which indicates that about 380,000 years after $t = 0$ 4D spacetime's temperature variations were approximately 1 part in 100,000. The amplitude of the fluctuations of the angular power spectrum of the CMB

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[74] Roger Penrose estimated the odds of achieving a homogeneous and isotropic 4D spacetime at $t = 0$ as approximately 10^10^123 to 1. See (Penrose, 2006). Since the near-maximal homogeneity and isotropy of 4D spacetime at $t = 0$ emerge intrinsically from Heat Death and the DO's integrated ontological and dynamic structure, the DO odds approach one.
[75] (Guth, 1981).

indirectly supports the conclusion that 4D spacetime was nearly homogeneous and isotropic at or near $t = 0$. The near-zero curvature parameter (Ω_k is -0.0005 ± 0.0005) measured at the last scattering surface supports the conclusion that 4D spacetime was within 0.1% of being flat and is consistent with the DO model's explanation that the collapse process at Heat Death preserves the flatness of 4D spacetime at $t = 0$.

The DO's resolution of the causality problem is premised upon four critical factors. First, the DO replaces the concept of an initial singularity at $t = 0$ with a discrete 4D spacetime. Second, the near maximal homogeneity and isotropy of the Universal Bell Energy Field at Heat Death is an internal physical process caused by the expansion and cooling of 4D spacetime over extremely long-time scales. Expansion and cooling are intrinsic physical processes governing 4D spacetime. Third, the instantaneous collapse of the Universal Bell Energy Point at Heat Death causes the generalized localization of the Universal Bell Energy Field at $t = 0$. The instantaneous nature of collapse ensures that localization occurs simultaneously across all of 4D spacetime. Any deviation in timing would introduce anisotropies or break causal continuity, undermining isotropy and homogeneity at $t = 0$. [76] Finally, at $t = 0$, the uniform size and shape of Discrete Spheres is critical. The uniformity ensures that no directional biases or density variations disrupt the homogeneity and isotropy of 4D spacetime at t = 0.

8.6. The Flatness Problem

The flatness of 4D spacetime's spatial curvature and its sensitivity to minor deviations from flatness (from k = 0 to either k =1 or k = -1) at or near $t = 0$ is known as the flatness problem. Since the value of k is calculated by Ω, and Ω is defined as $\Omega_{\text{total}} = \frac{\rho_{\text{total}}}{\rho_c}$, the total energy density of 4D spacetime at or near $t = 0$ must be extraordinarily close to the critical density p_c to ensure spatial flatness.

While the DO model does not provide a theoretical basis or physical data explaining why the total energy density of the universe has the particular values it does, it avoids reliance on ad hoc assumptions, fine-tuning, or perturbative techniques to maintain flatness.[77] The homogeneity and isotropy of 4D spacetime at $t = 0$, along with its intrinsic flatness, are functions of 1) the DO's tightly integrated ((3 x N) + 3) framework, 2) the uniform size, shape, and energy of Discrete Spheres, 3) the Bell Identity, 4) the near-maximal homogeneity and isotropy of 4D spacetime at Head Death, 5) the instantaneous collapse of the Universal Bell Energy Point in the Planck Dimension and 6) the generalized localization of the 4D spacetime's Universal Bell Field at $t = 0$.

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[76] The existence of anisotropies and inhomogeneities at Heat Death and $t = 0$ supports the formation of the large-scale structure of 4D spacetime. See (Le´on et al., 2014); (Okon & Sudarsky 2017); (Pérez et al., 2006); (Sudarsky, 2010).

[77] See generally (Wald, 2006).

8.7. Discrete Spheres, the Cosmological Constant, and Dark Energy

Under the DO model, each Discrete Sphere is structurally inert, has an identical size and shape, and contains a very small amount of constant intrinsic energy (CIE). Discrete Spheres do not interact with matter or radiation, are unaffected by gravity or the collapse of the Universal Bell Energy Point (ΩQS), and their CIE is invariant across 4D spacetime.

Cumulatively, the CIE of Discrete Spheres is the ontological source of Λ (Ω_{DS}), and its uniform energy density is expressed under the EFE as $\rho_\Lambda = \frac{\Lambda c^2}{8\pi G}$.[78] Consequently, the energy density per unit volume of Discrete Spheres equals the energy density per unit volume of the Λ ($\rho_{DS} = \rho_\Lambda$). The equation of state for Discrete Spheres is *w* = -1, representing the negative pressure of the Λ. Accordingly, Discrete Spheres affect not only 4D spacetime's curvature but also its rate of expansion.

Together, the gradual evolution of 4D spacetime into a pre-existing substructure of Discrete Spheres and the incremental increase in 4D spacetime's total energy budget provides an ontological alternative to the EFE's "internal stretching" into "nothing." As 4D spacetime expands into pre-existing Discrete Spheres, each sphere's CIE increases 4D spacetime's total energy budget without violating global energy conservation.[79] Instead, it reflects 4D spacetime's expansion into a pre-existing space.

Moreover, the expansion into a pre-existing space clarifies why 4D spacetime's expansion rate has increased over time. Since the equation of state for Discrete Spheres is *w* = -1, implying a negative pressure, their share of 4D spacetime's total energy budget grows as more Discrete Spheres come within 4D spacetime's bounds. Accordingly, experimental l evidence supports 4D spacetime's accelerated expansion without resorting to Dark Energy.[80]

9. Coda: The Quantum-Classical Divide

Finally, the DO framework highlights the ontological and dynamic separation between physical systems in the Planck Dimension and a discrete 4D spacetime. The Planck Dimension lacks a time dimension and spatial volume and is not governed by 4D spacetime's laws. Its only source of dynamic movement is collapse. In the Planck Dimension, a quantum state's single Bell Energy Point represents its quantum observables, but a Bell Energy Point does not support relational properties, like the *chairness* of a chair or the *aliveness* of a cat.

In contrast, 4D spacetime has a time dimension, space, and volume and is fully governed by its physical laws. Although a quantum state's observables (regardless of the quantum state's

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[78] The uniform distribution of the CIE of Discrete Spheres has no local gravitational effects.

[79] Discrete Spheres drive expansion and preserve flatness. As 4D spacetime expands into Discrete Spheres, the Hubble parameter dynamically adjusts to maintain ρ_{total} and ρ_c equilibrium.

[80] See (Riess et al., 1998).

size) appear in its Bell Energy Field, 4D spacetime also supports relational properties, like the solidity, shape, and color of a chair or cat aliveness. The relational properties between Bell Spheres in 4D spacetime emerge from 4D spacetime's ontology, dynamics, and laws, not from a quantum states Bell Point observables. Although a quantum state's observables in 4D spacetime can be determined under the proper conditions (a Stern-Gerlach experiment), 4D spacetime's relational properties are not determined by the quantum state's observables but by 4D spacetime's ontology, dynamics, and physical laws.

For instance, in the Schrödinger cat experiment, assume that the radioactive atom's quantum state is a superposition, represented by its Bell Energy Point and Bell Energy Field. After the instantaneous collapse of the atom's Bell Energy Point, the quantum state localizes to one outcome: the cat is "dead." Following the collapse, the cat's status is irreversible; there is no physical path back to "alive." Conversely, if collapse never occurs, the cat remains alive. The cat's status is relational, based on the status of its constituent quantum states' interactions under 4D spacetime's laws before, during, and after the experiment.

Moreover, in 4D spacetime, all quantum states evolve deterministically under GR and SR. Determinism extends to both quantum superpositions and their relational properties. Crucially, a quantum state's superposition remains subject to linear, relativistic evolution. However, the collapse of a Bell Energy Point introduces probability by determining which subset of Bell Spheres becomes localized in 4D spacetime.

The inability to quantize gravity reinforces this principle. Like other relational properties, gravity arises purely from relational configurations in 4D spacetime. Its curvature depends on the relational properties of mass, energy, and pressure, not the observables of a quantum state's Bell Energy Point.

10. Conclusion

The DO model's explanatory depth is premised on a novel physical and dynamic framework that systematically addresses and unites the most difficult issues in modern physics across scales and domains. Built on a substructure of Discrete Spheres and the SOAN, the DO's integrated ((3 x N) + 3) ontology replaces GR's continuous 4D spacetime manifold with a discrete, curved 4D spacetime and substitutes mathematical spaces with an ontic, ultra-high-dimensional (3 x N) Planck Dimension. Without the aid of ad hoc assumptions, fine-tuning, or perturbative techniques, the DO model supports a single ontological and dynamic framework and set of physical laws that unite and govern GR, SR, GQ, QM, the arrow of time, the cosmological constant Λ and 4D spacetime's Heat Death and instantaneous emergence at $t = 0$.

The explanatory depth of a non-temporal, non-spatial SOAN supports the Planck Identity's one-to-one identity and mapping between the Discrete Spheres that form 4D spacetime and the Planck Dimension. In turn, the Bell Identity and Bell Spheres ensure that the physical attributes of a quantum state, including its energy, are dynamically represented in both domains.

Significantly, the Bell Identity's mirroring function supports the linear evolution of quantum states in 4D spacetime and their instantaneous collapse in the Planck Dimension.

The DO framework offers new perspectives on unresolved questions in physics. It eliminates infinities associated with singularities through discretization, resolves the black hole information paradox by preserving quantum state information in the Planck Dimension, and explains why gravity is a local, relational phenomenon. The model provides a physical explanation for 4D spacetime's irreversible arrow of time and redefines the cosmological constant Λ as the intrinsic energy density of Discrete Spheres. The model also resolves 4D spacetime's homogeneity, isotropy, horizon, and flatness problems based on its instantaneous transition from Heat Death to $t = 0$. Finally, while quantum states are mirrored across domains, classical properties, like the aliveness of a cat, are exclusively governed by the relational ontology and dynamics of 4D spacetime. Classical determinism and quantum probability are not contradictory but arise from a single, integrated framework.

Discretized physical laws support the DO framework while preserving GR's background independence and causal structure as well as SR's physical constraints.

The DO model invites further exploration by challenging conventional assumptions. The model offers a foundation for a deeper understanding of the universe's fundamental nature, potentially bridging quantum and classical domains across all scales with a high degree of coherence and explanatory depth.

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Appendix A – Mathematical Formalisms

The following discrete mathematical formalisms support the DO's unified ((3 x N) + 3) structure and dynamics. Sections 1 and 2 are textbook formulations. Note that for simplicity and accessibility, the DO model uses standard continuous formulations in Section 8 above.

1. Special Relativity

Einstein's theory of SR is modified to conform with a discrete 4D spacetime.

1.1 Discrete Maxwell Equations

Purpose:

Maxwell's equations use discrete differential equations to describe electric and magnetic fields for Discrete Spheres in 4D spacetime.

Equations:

A. Gauss's Law for Electricity:

$$\nabla \cdot \boldsymbol{E}_{ijkl} = \frac{\boldsymbol{\rho}_{ijkl}}{\boldsymbol{\epsilon}_0}$$

B. Gauss's Law for Magnetism:

$$\nabla \cdot \boldsymbol{B}_{ijkl} = \boldsymbol{0}$$

C. Faraday's Law of Induction:

$$\nabla \times \boldsymbol{E}_{ijkl} = -\frac{\partial \boldsymbol{B}_{ijkl}}{\partial \boldsymbol{t}}$$

D. Ampère’s Law (with Maxwell’s correction):

$$\nabla \times \boldsymbol{B}_{ijkl} = \mu_0 \boldsymbol{J}_{ijkl} + \mu_0 \epsilon_0 \frac{\partial \boldsymbol{E}_{ijkl}}{\partial \boldsymbol{t}}$$

1.2 Discrete Dirac Equation

Purpose:

The Dirac equation uses discrete spinor fields and gamma matrices to describe fermion behavior, including spin and relativistic fields.

Equation:

$$i\gamma^0 \frac{\psi_{i,j+1} - \psi_{i,j}}{\Delta t} + i \sum_{k=1}^{3} \gamma^k \frac{\psi_{i+k,j} - \psi_{i-k,j}}{2\Delta x} - m\psi_{i,j} = 0$$

The equation for an N-body quantum state:

$$\boldsymbol{i}\hbar \frac{\partial \boldsymbol{\Psi}_{\boldsymbol{n}}(\boldsymbol{t})}{\partial \boldsymbol{t}} = \sum_{\boldsymbol{j}=\boldsymbol{1}}^{\boldsymbol{N}} \left(\boldsymbol{c} \alpha_{\boldsymbol{j}} \Delta_{\boldsymbol{j}} + \beta_{\boldsymbol{j}} \boldsymbol{m}_{\boldsymbol{j}} \boldsymbol{c}^2 \right) \boldsymbol{\Psi}_{\boldsymbol{n}}(\boldsymbol{t})$$

1.3 Discrete Klein-Gordon Equation

Purpose:

The Klein-Gordon equation uses second-order differential equations to model spin-0 particles in a relativistic context and to describe scalar field evolution.

Equation:

$$\frac{\phi_{i+1,j} - 2\phi_{i,j} + \phi_{i-1,j}}{\Delta x^2} + \frac{\phi_{i,j+1} - 2\phi_{i,j} + \phi_{i,j-1}}{\Delta t^2} + m^2\phi_{i,j} = 0$$

The equation for an N-body quantum state:

$$\sum_{n=1}^{N}\left(\frac{\phi_{i_n+1,j} - 2\phi_{i_n,j} + \phi_{i_n-1,j}}{\Delta x^2} + \frac{\phi_{i_n,j+1} - 2\phi_{i_n,j} + \phi_{i_n,j-1}}{\Delta t^2} + m^2\phi_{i_n,j}\right) = 0$$

2. General Relativity

The laws of GR are predicated on a continuous differentiable 4D spacetime manifold. Accordingly, the following equations integrate GR within the context of the DO's discrete 4D spacetime.

2.1 Modified Regge Calculus for a Discrete 4D Spacetime

Purpose:

The Modified Regge calculus describes GR's spacetime curvature within the DO's discrete Discrete Sphere framework. In this context, spacetime is composed of Discrete Spheres rather than a continuous manifold. Deficit angles at each Discrete Sphere represent the curvature of 4D spacetime.

Equation:

$$\sum_{\text{Discrete Spheres}} V_{\text{PS}}\delta_{\text{PS}} + \Lambda V_{\text{PS}} = 2\kappa \sum_{\text{Discrete Spheres}} T_{\text{PS}} + \rho\Lambda V_{\text{PS}}$$

2.2 Discrete Einstein Field Equations

Purpose:

The discretization of Einstein's Field Equations describes how mass and energy influence the curvature of discrete spacetime.

Equation:

$$\sum_j V_j \delta_j = 2\kappa \sum_j T_j V_j$$

2.3 Modified Dirac Equation for Curved Discrete 4D Spacetime:

Purpose:

The Dirac equation has been modified for a curved spacetime in a discrete 4D spacetime framework to ensure accurate descriptions of fermionic fields in a relativistic context.

Equation:

$$\boldsymbol{i\gamma^{\mu} D_{\mu} \psi - m\psi = 0}$$

The equation for an N-body quantum state:

$$\sum_{n=1}^{N} \left(i\gamma^0 \frac{\psi_{i_n,j+1} - \psi_{i_n,j}}{\Delta t} + i \sum_{k=1}^{3} \gamma^k \frac{\psi_{i_n+k,j} - \psi_{i_n-k,j}}{2\Delta x} - m\psi_{i_n,j} \right) = 0$$

2.4 Modified Klein-Gordon Equation for Curved Discrete 4D Spacetime:

Purpose:

The Klein-Gordon equation has been modified for curved spacetime in a discrete 4D spacetime framework to ensure spin-0 particles are properly modeled in a relativistic context.

$$\sum_{\mu,\nu} g_{i,j}^{\mu\nu} \left(\frac{\phi_{i+\hat{\mu},j} - 2\phi_{i,j} + \phi_{i-\hat{\mu},j}}{\Delta x^2} + \frac{\phi_{i,j+\hat{\nu}} - 2\phi_{i,j} + \phi_{i,j-\hat{\nu}}}{\Delta t^2} \right) + \frac{m^2 c^2}{\hbar^2} \phi_{i,j} = 0$$

The equation for an N-body quantum state:

$$\sum_{k=1}^{N}\left(\sum_{\mu,\nu} g_{i,j,k}^{\mu\nu}\left(\frac{\phi_{i+\hat{\mu},j,k} - 2\phi_{i,j,k} + \phi_{i-\hat{\mu},j,k}}{\Delta x^2} + \frac{\phi_{i,j+\hat{\nu},k} - 2\phi_{i,j,k} + \phi_{i,j-\hat{\nu},k}}{\Delta t^2}\right) + \frac{m_k^2 c^2}{\hbar^2}\phi_{i,j,k}\right) = 0$$

3. Dynamic Evolution of Single and N-Body Quantum States in 4D Spacetime

Purpose:

The dynamic evolution of single and N-body quantum states in a discrete 4D spacetime and the Bell Identity's continuous mapping of quantum states in 4D spacetime and the Planck Dimension ensures quantum coherence and unitarity. Changes in a quantum state's Bell Field(s) in 4D spacetime are instantaneously mirrored by corresponding changes in the quantum state's single Bell Point in the Planck Dimension.

3.1 General Law of Quantum State Evolution under the DO Model

Equations:

$$DE: \phi_{i,n}^{4D} \leftrightarrow \text{Bell Identity } \psi_n^{PS}$$

$$\delta\phi_{i,n}^{4D} = \left(\phi_{i,n}^{4D}, \phi_{i,n+1}^{4D}, \ldots, t\right)$$

$$\delta\psi_n^{PS} = \left(\psi_n^{PS}, \psi_{n+1}^{PS}, \ldots, t\right)$$

Dynamic Process:

$$DE: \left(\phi_{i,n}^{1,4D}, \phi_{i,n}^{2,4D}, \ldots\right) \leftrightarrow \text{Bell Identity } \psi_n^{PS}$$

$$DE: \left(\phi_{i,n}^{A,4D}, \phi_{i,n}^{B,4D}, \ldots\right) \leftrightarrow \text{Bell Identity } \psi_n^{PS}$$

Definitions:

DE: The dynamic evolution of single or N-body quantum state in 4D spacetime.

Bell Identity: The one-to-one identity and mapping between a Bell Sphere in 4D spacetime and the Planck Dimension. The same Bell Spheres that form a quantum state's Bell Field(s) in 4D spacetime and also form its single Bell Point in the Planck Dimension.

$(\boldsymbol{i})$**:** Time variable in 4D spacetime.

$(\boldsymbol{n})$: The number of Bell Fields that comprise a quantum state in 4D spacetime.

$(\boldsymbol{\phi}_{i,n}^{\mathbf{4D}})$**:** Represents the number of Bell Fields that comprise a single or N-body quantum state at any given moment of time in 4D spacetime.

$(\boldsymbol{\phi}_{i}^{\mathbf{1,4D}})$: Represents Bell Field 1 in connection with a single body quantum state at any given moment in time in 4D spacetime.

$(\boldsymbol{\phi}_{i}^{\mathbf{2,4D}})$: Represents Bell Field 2 in connection with a single body quantum state at any given moment in time in 4D spacetime.

$(\boldsymbol{\phi}_{i}^{\mathbf{A,4D}})$**:** Represents Bell Field A in connection with an N-body quantum state in 4D spacetime

$(\boldsymbol{\phi}_{i}^{\mathbf{B,4D}})$**:** Represents Bell Field B in connection with an N-body quantum state in 4D spacetime.

$(\boldsymbol{\psi}^{\mathbf{PS}})$**:** Represents a single or N-body quantum state's single Bell Point in the Planck Dimension.

3.2 General Law of Single Quantum State Evolution Under the DO Model

Equation:

$$\boldsymbol{DE}: \boldsymbol{\phi}_{i}^{\mathbf{4D}} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{\mathbf{PS}}$$

Dynamic Process

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_{i}^{\mathbf{1,4D}}, \boldsymbol{\phi}_{i}^{\mathbf{2,4D}}, \dots\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{\mathbf{PS}}$$

3.3 General Law of N-body Quantum State Evolution Under The DO Model

Equation:

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_{i}^{\boldsymbol{A},\mathbf{4D}}, \boldsymbol{\phi}_{i}^{\boldsymbol{B},\mathbf{4D}}, \dots\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{\mathbf{PS}}$$

Dynamic Process**:**

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_i^{A,4D}, \boldsymbol{\phi}_i^{B,4D}, \dots\right) \to \left(\boldsymbol{\phi}_{i+1}^{A,4D}, \boldsymbol{\phi}_{i+1}^{B,4D}, \dots\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}_{i+1}^{PS}$$

3.4 Dynamic Evolution – Bohm/EPR Experiment Under The DO Model

Equation:

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_i^{A,4D}, \boldsymbol{\phi}_i^{B,4D}\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{PS}$$

Dynamic Process:

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_i^{A,4D}, \boldsymbol{\phi}_i^{B,4D}\right) \to \left(\boldsymbol{\phi}_{i+1}^{A,4D}, \boldsymbol{\phi}_{i+1}^{B,4D}\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}_{i+1}^{PS}$$

4. The Planck Dimension Collapse Operator

Purpose:

Section 4 addresses the physical mechanisms underlying the instantaneous collapse of single and N-body quantum states' Bell Energy Points.

4.1 General Law of Quantum State Collapse Under The DO Model

Equations:

$$\boldsymbol{C}: \boldsymbol{\psi}_j^{PS} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\phi}_{i,j}^{4D}$$

$$\boldsymbol{\delta}\left(\boldsymbol{\psi}_j^{PS} - \boldsymbol{\psi}_{j'}^{PS}\right)$$

$$\boldsymbol{\delta}\left(\boldsymbol{\phi}_{i,j}^{4D} - \boldsymbol{\phi}_{i,j'}^{4D}\right)$$

Collapse Process:

$$\boldsymbol{T} \to \boldsymbol{\psi}_j^{PS} \to \boldsymbol{\psi}_{j'}^{PS} \to \left(\boldsymbol{\phi}_{i,j'}^{4D}\right)$$

$$\boldsymbol{T} \to \boldsymbol{\psi}_j^{PS} \to \boldsymbol{\psi}_{j'}^{PS} \to \left(\boldsymbol{\phi}_{i,j'}^{4D}\right)$$

$$\boldsymbol{T} \to \boldsymbol{\psi}_j^{PS} \to \left(\boldsymbol{\psi}_{j_1'}^{PS}, \boldsymbol{\psi}_{j_2'}^{PS}, \dots, \boldsymbol{\psi}_{j_N'}^{PS}\right) \to \left(\boldsymbol{\phi}_{i,j_1'}^{4D}, \boldsymbol{\phi}_{i,j_2'}^{4D}, \dots, \boldsymbol{\phi}_{i,j_N'}^{4D}\right)$$

Definitions:

C: The collapse operator describes the process initiated by a 4D spacetime trigger that leads to the instantaneous collapse of a single or N-body quantum state's Bell Energy Point in the Planck Dimension. Following the collapse:

A single quantum state will form a single Bell Point in the Planck Dimension and a single Bell Field in 4D spacetime.

An N-body quantum state will form multiple independent Bell Points in the Planck Dimension and multiple corresponding Bell Fields in 4D spacetime.

Each resulting Bell Point and corresponding Bell Field will be a subset of the original Bell Point and Bell Field(s).

The operator also reflects the effect of the Bell Identity, which ensures an instantaneous and simultaneous reduction in the number of Bell Spheres that comprise the single or N-body quantum state's new Bell Field(s) in 4D spacetime, causing the generalized localization of the new Bell Field(s).

T: The 4D spacetime trigger that initiates the collapse of the quantum state's Bell Energy Point in the Planck Dimension.

Bell Identity: Ensures a one-to-one correspondence between the Bell Spheres that form a Bell Point in the Planck Dimension and one or more Bell Fields in 4D spacetime.

For a single quantum state, the Bell Identity ensures an instantaneous reduction in the number of Bell Spheres that form a single new Bell Point and Bell Field.

For an N-body quantum state, the Bell Identity ensures an instantaneous reduction in the number of Bell Spheres that form multiple Bell Points and corresponding Bell Fields.

($\boldsymbol{\psi}$): The wave function of the quantum state.

($\boldsymbol{j}$): Represents the initial number of Bell Spheres that comprise the quantum state before collapse.

($\boldsymbol{j'}$): Represents the reduced number of Bell Spheres that comprise the quantum state after collapse.

($\boldsymbol{i}$): Time variable in 4D spacetime.

($\boldsymbol{\phi}$) Represents the quantum state's Bell Field(s) in 4D spacetime.

(δ): Delta function indicating the change or difference.

(PS): the Planck Dimension

(4D): 4D spacetime

(ψ_j^{PS})**:** The quantum state before the collapse of its single Bell Energy Point.

$(\psi_{j'}^{\mathrm{PS}})$**:** The quantum state's collapsed state following the collapse of its Bell Energy Point. Following the collapse, a single quantum state will form a single new Bell Point, and an N-body quantum state will form two or more new Bell Points. Each new Bell Point is a subset of the initial Bell Spheres that formerly comprised the quantum state's single Bell Point.

$\left(\Phi_{i,j}^{4D}\right)$: The quantum state's Bell Field in 4D spacetime before collapse.

$\left(\Phi_{i,j'}^{4D}\right)$: Following the collapse of the quantum state's Bell Energy Point, a single quantum state will form a single new Bell Field in 4D spacetime, and an N-body quantum state will form two or more new Bell Fields in 4D spacetime. The new Bell Field(s) are generally localized in 4D spacetime and are subsets of the original Bell Fields that comprised the quantum state.

Delta Function *(δ):*

– The first delta function represents the precise reduction in the number of Bell Spheres that form one or more of the quantum state's Bell Points in the Planck Dimension following the quantum state's collapse.

– The second delta function indicates the identical reduction in the number of Bell Spheres that form one or more of the quantum state's Bell Fields in 4D spacetime following the generalized localization of the new Bell Field(s).

4.2 General Law of Single Quantum State Collapse Under The DO Model

Equation:

$$C: \psi_j^{\mathrm{PS}} \leftrightarrow \textbf{Bell Identity } \varphi_{i,j}^{\mathrm{4D}}$$

$$\delta\left(\psi_j^{\mathrm{PS}} - \psi_{j'}^{\mathrm{PS}}\right)$$

$$\delta\left(\varphi_{i,j}^{\mathrm{4D}} - \varphi_{i,j'}^{\mathrm{4D}}\right)$$

Collapse Process:

$$T \rightarrow \Psi_j^{\mathrm{PS}} \rightarrow \Psi_{j'}^{\mathrm{PS}} \rightarrow \left(\Phi_{i,j'}^{\mathrm{4D}}\right)$$

4.3 General Law of N-Body Quantum State Collapse Under The DO Model

Equation:

$$C: \psi_j^{\mathrm{PS}} \leftrightarrow \textbf{Bell Identity } \varphi_{i,j}^{\mathrm{4D}}$$

$$\boldsymbol{\delta}\left(\boldsymbol{\psi}_{\boldsymbol{j}}^{\mathbf{PS}} - \boldsymbol{\psi}_{\boldsymbol{j}'}^{\mathbf{PS}}\right)$$

$$\boldsymbol{\delta}\left(\boldsymbol{\varphi}_{\boldsymbol{i,j}}^{\mathbf{4D}} - \boldsymbol{\varphi}_{\boldsymbol{i,j}'}^{\mathbf{4D}}\right)$$

Collapse Process:

$$\boldsymbol{T} \rightarrow \boldsymbol{\Psi}_{\boldsymbol{j}}^{\mathbf{PS}} \rightarrow \left(\boldsymbol{\Psi}_{\boldsymbol{j}_1'}^{\mathbf{PS}}, \boldsymbol{\Psi}_{\boldsymbol{j}_2'}^{\mathbf{PS}}, \dots, \boldsymbol{\Psi}_{\boldsymbol{j}_N'}^{\mathbf{PS}}\right) \rightarrow \left(\boldsymbol{\Phi}_{\boldsymbol{i,j}_1'}^{\mathbf{4D}}, \boldsymbol{\Phi}_{\boldsymbol{i,j}_2'}^{\mathbf{4D}}, \dots, \boldsymbol{\Phi}_{\boldsymbol{i,j}_N'}^{\mathbf{4D}}\right)$$

4. Quantum State Collapse – Bohm/EPR Experiment Under The DO Model

Equation:

$$\boldsymbol{C}: \boldsymbol{\Psi}_{\boldsymbol{AB}}^{\mathbf{PS}} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\varphi}_{\boldsymbol{i,j}}^{\boldsymbol{A,B,4D}}$$

$$\boldsymbol{C}: \boldsymbol{\psi}_{\boldsymbol{AB}}^{\boldsymbol{PS}} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\varphi}_{\boldsymbol{i,j}}^{\boldsymbol{A,B,4D}}$$

$$\boldsymbol{\delta}\left(\boldsymbol{\psi}_{\boldsymbol{AB}}^{\boldsymbol{PS}} - \boldsymbol{\psi}_{\boldsymbol{A'B'}}^{\boldsymbol{PS}}\right)$$

$$\boldsymbol{\delta}\left(\boldsymbol{\varphi}_{\boldsymbol{i,j}}^{\boldsymbol{A,B,4D}} - \boldsymbol{\varphi}_{\boldsymbol{i,j}}^{\boldsymbol{A'B',4D}}\right)$$

Collapse Process:

$$\boldsymbol{T} \rightarrow \boldsymbol{\Psi}_{\boldsymbol{AB}}^{\mathbf{PS}} \rightarrow \left(\boldsymbol{\Psi}_{\boldsymbol{A'}}^{\mathbf{PS}}, \boldsymbol{\Psi}_{\boldsymbol{B'}}^{\mathbf{PS}}\right) \rightarrow \left(\boldsymbol{\phi}_{\boldsymbol{i,j'}}^{\boldsymbol{A,4D}}, \boldsymbol{\phi}_{\boldsymbol{i,j'}}^{\boldsymbol{B,4D}}\right)$$

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