Through the Wormhole on Spacetime Surface: Early History and Main Concepts of Topological Geometrodynamics Theory (TGD)

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Alas, a few years ago,
I should have said 'my universe:'
but now my mind has been opened
to higher views of things.[1]
Edwin A. Abbott

Introduction

The relationship between geometry and physics is one of the most fruitful and fascinating topics in the history of science. From ancient Mediterranean civilizations to the modern era, geometry has served as a source of insight for metaphysical contemplation and the discovery of natural phenomena.

In this essay, I will explore some of the major developments in geometry and physics, with a special focus on the work of Dr. Matti Pitkänen, the founder of Topological Geometrodynamics (TGD). This novel theory employs mathematical concepts to unify quantum mechanics and general relativity with the Standard Model of particle physics.

In the first section, I will review historical milestones in geometry and physics relevant to the key issues in TGD theory. These epochs have led us to relativity, quantum mechanics, the Standard Model, string models, and various unification attempts. I will also introduce the concept of topology, which is the study of continuous deformations. Topology plays a vital role in many areas of physics and mathematics, as well as in TGD.

In the central section, I will present an interview with Dr. Pitkänen, in which he shares his personal and professional journey in developing TGD. He explains how he, a) was initially motivated by the global energy definition problem in general relativity, b) was influenced by John Wheeler's ideas on geometrodynamics, c) discovered a higher-dimensional embedding hyperspace suitable for unifying the Standard Model, quantum mechanics, and relativity, d) faced challenges in achieving path integrals for

[1] Edwin Abbott, Flatland: A Romance of Many Dimensions, p.8 (1884)

the required 4-D general coordinate invariance, e) incorporated twistors into his theory, f) introduced the notions of the World of Classical Worlds and Zero Energy Ontology to address problems related to quantum TGD and time, and g) found a dual aspect for the geometrization of physics from number theory, p-adic physics, and Adelic physics, which also forms a theory of cognition and consciousness within the same framework.

This segment particularly emphasizes explaining the fundamentals of general relativity and its conservation laws with related symmetries, underscoring their relevance to the inception of TGD, which was sparked by questions within this domain. Noether's theorems play a central role in this excursion.

In the last section, I will provide additional information on TGD, such as its main publications, websites, blogs, videos, podcasts, and other resources. I have also given a section about the research methodology I am pursuing.

In the appendices, I will offer an extensive vocabulary, a short timeline, and a concept map to serve as helpful tools for readers seeking to understand the complex topics discussed in the essay better. Appendices 4-5 are more technical sub-studies for Killing vectors and pseudotensors. Appendix 6 deals with the definition of the Theory of Everything. Appendix 7 gives a short version of this essay for people in a rush. Finally, the bibliography and index are collected to the end.

While this manuscript is not a comprehensive discussion on TGD—a task that could quickly require thousands of pages—it aims to fill a notable gap by offering curated introductory material and shedding light on aspects of a unique unified theory of fundamental physics that have yet to be explored in this format.

Part I: Geometry to Rule Them All

Geometry, commonly seen as the mathematical language of space and form, has deepened our understanding of immediate surroundings and the expansive cosmos. This mathematical domain employs tools like rulers, compasses, coordinates, dimensional objects, shapes, and transformations to elucidate spatial relationships.

The roots of geometry extend to ancient civilizations where rudimentary land measurement techniques, astronomical calculations, and navigation were used. The systematic and organized principles of geometry, however, were established by the ancient Greek scholar Euclid in his "Elements" series around 300 BC. In this work, Euclid offered rigorous definitions, postulates, and axioms that laid the logical groundwork for geometry. He derived a set of theorems and corollaries from these foundations that covered plane geometry, solid geometry, number theory, and proportion. Euclid's work has mostly stood the test of time, influencing mathematical thought for over two millennia.

Fast-forwarding two thousand years from Euclid's time, geometry underwent a transformation with the introduction of Cartesian coordinates, a system devised by René Descartes and later adopted by Sir Isaac Newton and Gottfried Wilhelm Leibniz in their theory of infinitesimal calculus in the 17th and 18th century. This innovation heralded a new era in natural philosophy by fusing geometry with algebra, enriching our understanding of the physical world. The Cartesian system allowed for translating geometric problems into mathematical equations, simplifying symbolic manipulation and solution discovery.

In the mid-19th century, English mathematician and philosopher William Clifford took the symbiosis between geometry and algebra a step further. Clifford enhanced geometric language by expressing it in algebraic forms through what became known as Clifford algebra. Unlike Cartesian algebra, Clifford's framework unified various geometric entities within a single structure, including scalars, vectors, and bivectors—the latter being a type of geometric object that captures area, much like vectors capture length. The geometric product, a key operation in Clifford algebra, merged these entities, thereby streamlining the mathematics behind rotations and reflections in three dimensions. Clifford's contributions found applications in higher-dimensional spaces, relativity, and quantum mechanics, notably in the study of spinors—mathematical entities that describe particle spins—and the analysis of fermionic fields, which characterize a subset of subatomic particles in string models.

In the mid-19th century, German mathematician Bernhard Riemann expanded the scope of geometry beyond the Euclidean plane, exploring curved surfaces and higher dimensions. His foundational work in non-Euclidean geometry, where the parallel line axiom and the rule of triangle angles summing to 180 degrees no longer held, became instrumental in developing relativity theories.

Relativity

The discussion on relative motion began as early as the 17th century, most notably with the work of Galileo Galilei, an Italian astronomer, philosopher, and physicist.

Galileo's thought experiment laid out the basic principles that would later form the foundation for the theory of relativity. His Salviati thought experiment, presented in the book “Dialogue Concerning the Two Chief World Systems” in 1632, shows that the motion of various objects inside a stationary or uniformly moving ship appears the same to an external observer. For example, flying butterflies, jumping men, dripping water, or swimming fish in a bowl experience no change due to the uniform motion of the ship, provided the observed phenomena are below deck and thus isolated from external forces like wind and air resistance. In simple terms, two systems moving relative to each other without acceleration are equivalent.

This idea evolved into Galileo's relativity principle, focusing on relative motion characteristics. It postulates that the fundamental laws of physics are constant for observers in inertial frames, whether in motion or at rest. Two centuries later, in a broader sense, these principles found application in theories involving electromagnetic forces and the æther.

The understanding of relativity advanced further with the work of Hendrik Lorentz, a Dutch physicist and mathematician whose contributions spanned the late 19th and early 20th century. Lorentz focused on transformation equations, now known as Lorentz transformations. These equations describe how two observers' measurements of time and space are related, assuming they are moving at a constant velocity relative to each other. Through these equations, Lorentz alluded to the interconnection between time, space, and motion.

Around the same period, French mathematician and theoretical physicist Henri Poincaré also explored relativity. In his 1905 paper "The Principles of Mathematical Physics," Poincaré examined the principle of relativity, its interpretations, and its challenges. Engaged in discussions on the fundamental principles of physics, especially in the context of electromagnetism and motion, Poincaré contributed to the conversation on the relativity of simultaneity and the use of Lorentz transformations. His work set the stage for further developments by Einstein.

The theory of relative motion was already evolving in the scientific community when the German physicist Albert Einstein displayed a keen ability to identify and solve open problems in physics. In a productive culmination, he published four groundbreaking papers in 1905, one of which was the theory of special relativity (SR), released on September 26.

Einstein's theory of special relativity diverged from previous theories on relative motion by introducing two clear postulates: a) the laws of physics are invariant for all inertial observers, and b) the speed of light in a vacuum is constant for all observers, regardless of the motion of the light source or observer. This challenged the prevailing æther hypothesis and the notion of absolute simultaneity. Einstein's SR fused space and time into spacetime, showing that measurements of time and space depend on the relative motion between the observer and the event. This led to the physical interpretation of phenomena like time dilation and length contraction, which Lorentz had already speculated upon in the context of æther theories. Additionally, SR introduced the mass-energy equivalence principle, encapsulated by the equation $E = mc^2$, highlighting the convertibility of mass and energy.

While other prominent scientists of the era could have formulated SR, the theory of general relativity (GR) presented a unique challenge that perhaps only Einstein could have met. This perspective often omits the contributions of German physicist Max Abraham, Finnish physicist Gunnar Nordström, German mathematician David Hilbert, and Swiss mathematician Marcel Grossmann[2], all of whom were also working on a new theory of gravitation, and Einstein was in communication with them. The development of GR was not a solitary endeavor; it had

[2] "The collaboration of Einstein and Grossmann led to a ground-breaking paper: 'Outline of a Generalized Theory of Relativity and of a Theory of Gravitation,' which was published in 1913 and was one of the two fundamental papers which established Einstein's theory of gravity." Marcel Grossmann (wikipedia.org)

its proponents, even if many physicists were initially skeptical and did not see any future in Einstein's work with gravity.

Nordström's work[3], perhaps the most notable among the independent theories, became an unreferenced footnote in history due to its unsuccessful predictions concerning the behavior of light rays under gravitation and its lack of covariance compared to Einstein's theory. Nordström's theory was based on Minkowski's formulation of spacetime and scalar fields, whereas Einstein already employed tensors, which were more capable of describing gravity. Hilbert's work, in turn, was developed concurrently with Einstein's theory of gravity at its later formulation and was fundamentally inspired by Einstein's core ideas on gravity.

In 1915, Einstein presented his most refined thoughts on the 'force' of gravity within the framework of GR. He suggested that gravity could be understood as a manifestation of spacetime curvature caused by mass and energy, which blurred the traditional concept of force. Einstein needed to venture into new mathematical territories to substantiate his physical insights regarding the equivalence principle. The earlier realization was that all objects fall at the same rate in a vacuum, irrespective of their mass. For example, in a vacuum, a feather and a bowling ball dropped from a tower would reach the ground simultaneously, absent any resistance. Einstein's new principle maintained that the laws of physics must be uniform across all coordinate systems, not just in a freely falling, non-rotating laboratory but in a broader array of physical situations; inertial mass is identical to gravitational mass.

GR requires understanding two mathematical frameworks: a) differential geometry and b) tensor calculus. Differential geometry studies curves and surfaces in spaces of two or more dimensions, focusing on their properties under smooth deformations. Tensor calculus involves mathematical objects that generalize vectors and can describe physical quantities in a way that is independent of any particular coordinate system. These frameworks offer the tools needed to describe the interactions between mass-energy and the fabric of spacetime from any observer's perspective.

Initially hesitant, Einstein eventually integrated the work of his mathematics teacher, Minkowski, into his theories of relativity. Minkowski formulated a unified system for space and time to describe hyperbolic spacetime in Einstein's theories of

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[3] Galina Weinstein, The Einstein-Nordström Theory, 27 May 2012 (arxiv.org)

relativity. These areas of mathematics, previously largely separate from physics, provided Einstein with the tools to articulate his concept of a four-dimensional curved universe through field equations relating mass-energy to geometry.

The geometrization concept is intriguing. It posits that objects with mass, charge, and momentum can be understood as localized energy causing curvatures in a four-dimensional coordinate system. If everything traditionally considered physical things, fields, and particles can be expressed as geometric entities, does this suggest that the nature of reality is fundamentally mathematical? And do our methods of perception and measurement merely give the illusion of rigid bodies[4] with centers of mass-energy? These profound ontological questions remain a subject of ongoing research. A multidisciplinary approach involving philosophical rigor, empirical research, and mathematical modeling is essential for addressing such questions.

Newton unified the motion of terrestrial objects, like falling apples, with the orbital movements of celestial bodies under a single set of equations. This gave a concrete interpretation to the ancient hermetic axiom 'as above so below.' Einstein, however, extended this unification by merging space and time, entities long considered separate by natural philosophers.

While Newton might have had inklings of local causality, he left its application to gravity unresolved. Einstein picked up this challenge after his successful work with light quanta. His completed framework replaced Newton's instantaneous action-at-a-distance model of gravity with one rooted in local causality.

In Einstein's relativity theories, objects trace geodesics, the most straightforward paths through curved spacetime. This makes absolute time and simultaneity irrelevant due to the constant speed of light, which serves as the basis for signal causation. The principle of local causality is maintained: initial influences affect only immediate neighboring objects, with subsequent effects propagating up to 300,000 kilometers per second, affecting both gravitational and electromagnetic phenomena, including visible light.

The shift from Newtonian to Einsteinian mechanics is not without its complexities. GR is intricate, layered with mathematical formulations, physical interpretations, and ontological questions, some of which we will explore later.

[4] See Appendix 1: Core Terms for a clarification of terms like 'Rigid body.'

Quantum Mechanics

While GR governs large-scale phenomena, quantum mechanics (QM) rules the microscopic realm. The birth of QM dates back to the early 20th century when classical physics failed to explain certain behaviors at atomic and subatomic levels. Max Planck's quantization of energy in 1900, along with Einstein's explanation of the photoelectric effect in 1905, marked a significant departure from classical physics. Further developments in QM were fueled by contributions from physicists and mathematicians like Niels Bohr, Werner Heisenberg, Erwin Schrödinger, Max Born, Wolfgang Pauli, and Paul Dirac.

Geometry also plays a role in quantum mechanics, as evidenced by the formulation of the Dirac Equation, which integrates both quantum mechanics and special relativity to describe the behavior of fermions with spin-½, and the Yang-Mills Equation, which extends the concept of gauge invariance and geometry into the realm of quantum field theory (QFT), providing a framework for understanding the strong and weak nuclear forces. QFT, the foundation of the Standard Model of particle physics, employs group theory and differential geometry to describe elementary particle interactions. The structure of quantum states and the rules governing their evolution owe much to geometric principles encapsulated within an abstract infinite-dimensional space named after Hilbert, who shifted his focus to QM after working on relativity first. This shift of interest was widespread in the physics community, so much so that relativity theories became less attractive than QM for decades. Even Einstein received his Nobel prize in 1921 for explaining the photoelectric effect, which relates to QM, not relativity.

In the Hilbert space, each quantum state is represented as a vector. Physical quantities relevant to these states, like energy or momentum, are expressed as operators[5]. This abstract mathematical framework gives rise to quantum principles such as:

[5] An operator refers to a mathematical entity that acts on the vectors in a Hilbert space to produce other vectors or scalars within the same space. These operators embody the observable physical quantities: they transform a quantum state into another state or provide measurable values (eigenvalues) associated with these quantities. Specifically, operators are used to represent physical observables such as energy (Hamiltonian operator) or momentum (momentum operator), applying linear transformations that correspond to the measurement processes in quantum theory.

- **Superposition**: This principle states that a quantum system can exist in multiple states simultaneously, each with its associated probability until an observation (measurement) occurs. Superposition is a concept shared with classical wave mechanics but treated uniquely in QM.
- **Entanglement**: A phenomenon where particles in a quantum system become correlated so that one particle's state instantaneously correlates with another's state, no matter the distance separating them. This does not imply faster-than-light communication or influence, as the correlation is observed rather than used for signal propagation. The outcome of one measurement is instantaneously known once the other is measured, but this does not transmit any usable information faster than light.
- **Probability**: Quantum mechanics uses probability amplitudes, which are complex numbers associated with the likelihood of finding a system in a particular state. The square of the amplitude's magnitude gives the actual probability of an event occurring, a fundamental departure from classical probabilities. While classical probabilities sum directly, quantum probabilities (amplitudes) must be added and then squared, reflecting the wave-like interference patterns unique to quantum systems.
- **Decoherence**: This concept describes the transition of a quantum system to a classical state as it interacts with its environment. This causes the system to lose its quantum superposition and behave more predictably. Decoherence helps to explain why quantum effects are not generally observed in macroscopic objects.
- **Tunneling**: A quantum effect where particles have a probability of passing through potential barriers even when they lack the energy to do so in classical physics. This phenomenon is essential in various quantum technologies, such as scanning tunneling microscopes or quantum computing. It helps to explain several natural processes, such as nuclear fusion in stars or biological enzyme action in cells.
- **Quantum Jump**: This refers to the sudden, probabilistic transition from one quantum state to another, often resulting in the emission or absorption of energy in discrete quanta. These jumps are characterized by their whole number discretization, as the energy levels of quantum systems are quantized. In atomic systems, for instance, electrons jump between fixed orbits or energy levels, and the energy difference between these levels is emitted or absorbed as

a photon with a frequency directly proportional to the energy difference, reflecting the discrete nature of quantum states.

GR and QM represent contrasting paradigms: GR operates under smooth, continuous mechanics, while QM involves the discretization of quantum numbers (not spacetime inherently), quantum jumps, and entanglement. This disparity presents a challenge for those attempting to merge these theories. Either one must be modified, or a new framework that accommodates both GR and QM must be developed without compromising their current accuracy, applicability, and sophistication levels.

Standard Model and String Models

In the Standard Model, each type of elementary particle—be it a boson, quark, or lepton—corresponds to a unique field that permeates spacetime. These fields can be thought of as the fabric of the universe, with each particle type representing a specific vibrational pattern within this fabric.

Certain symmetries, known as gauge symmetries, govern the interactions among elementary particles. These symmetries dictate the laws of interaction and maintain the consistency of the physical laws that apply to the particles. Gauge symmetries are expressed through mathematical constructs called Lie groups, named after Norwegian mathematician Sophus Lie, who lived in the 17th century. Lie groups capture continuous symmetries and provide a geometric framework for understanding the structure and behavior of gauge fields mediating particle interactions.

The concept of gauge fields is formalized using the mathematical notion of fiber bundles, a key element in differential topology. In a fiber bundle, each point of a base space is connected to a unique geometric structure called a fiber. In particle physics, the base space represents spacetime, while the fibers correspond to the various possible states or configurations of a gauge field at each geometric point. This is the basis for describing particles as point-like in the Standard Model. Both matter particles called fermions and force carrier particles called bosons emerge from a synthesis of empirical data categorized by the features of the particles that have been collected in experiments over the last century and theoretical foundations. Fermions, comprising quarks and leptons, are distinguished by their half-integer spins and compliance with the Pauli exclusion principle. In contrast, bosons stand out for their integer spins and significantly for their derivation from symmetry group representations.

String models, often called String Theory, aim to unify QM and GR, and extend this geometric perspective. The basic entities are one-dimensional strings that vibrate in multi-dimensional spacetime rather than point-like particles. Like musical notes produced by a vibrating string, the various vibrational patterns of these strings are thought to correspond to different types of particles. The mathematics used to describe these vibrations and their interactions is steeped in geometry. It involves group theory, manifold topologies, and Riemann surfaces as strings moving through space, creating world sheets. So, particles in the string model have a more profound theoretical origin than in the Standard Model.

The Standard, Bosonic String, and Superstring Models emerged in the 1970s. When Einstein and contemporaries like Nordström, Hilbert, Theodor Kaluza, Max Born, Leopold Infeld, Hermann Weyl, Gustav Mie, and Dirac sought to unify electromagnetism and relativity, some even early atomic models, they lacked vital information unavailable until after the 1960s. Only electrons, protons, and photons, and a bit later, neutrons and positrons, were known at that time. Discoveries made post-1960, such as identifying quarks and gluons, the partial understanding of strong interaction color forces, the Higgs mechanism, and the confirmation of the universe's expansion, were gaps in previous knowledge and stymied unification efforts.

New insights provided by the understanding of strong and weak nuclear forces, the principles of spontaneous symmetry breaking, and the non-local behavior of entangled particles have opened perplexing new avenues for the unification of GR and QM. These complexities have left a highly intricate puzzle for future researchers to solve.

Topology

Topology, sometimes called rubber-sheet geometry, is a branch of mathematics that originated in the 18th century. Its pioneering contributions came from Swiss mathematician Leonhard Euler, German mathematician August Ferdinand Möbius, and Riemann.

Unlike classical geometry, which focuses on distances and angles, topology is concerned with properties of space that remain unchanged under continuous transformations. A key concept in topology is the idea of open sets, collections of points defined by the condition that any point in the set has a neighborhood entirely within that set. Neighborhoods are sets around a point extending to a certain limit, embodying the idea of closeness without requiring a metric for measuring distance. In topological terms, continuity means that when points from one set map onto another, points that are proximate in the original set remain proximate in the target set. This preserves the essential relationships between topological spaces during transformations. A set of points becomes a topological space when one specifies which subsets are open. These open sets satisfy certain conditions to formalize our intuitive understanding of geometric concepts like convergence and continuity.

A classical question in topology concerns the number of holes in a straw. Typically, a straw is modeled as a cylinder. In topology, it is considered equivalent to a torus, a doughnut shape, or a coffee cup with one handle because one can be deformed into the other without tearing or gluing. Both have a single hole and are topologically equivalent. Defining open sets becomes a practical step when examining the straw's surface as a topological space. In this context, an open set is a collection of points on the straw's surface, where each point is surrounded by a small region lying entirely within the set, away from the boundary. This concept of open sets is crucial as it helps understand how the surface behaves under continuous transformations. For instance, stretching or bending the straw is a continuous transformation as it does not add or remove holes. Such transformations retain the topological equivalence between the original and transformed object, emphasizing the value of open sets in studying continuous transformations without resorting to non-continuous operations like tearing or gluing.

Theoretical physics took a nuanced turn in the 1960s when American scientist John Archibald Wheeler introduced the term 'geometrodynamics.' Wheeler proposed the concept of quantum or spacetime foam, suggesting that spacetime might have a fluctuating, intricate structure at extremely tiny scales, constantly undergoing topological changes.

The relationship between topology and geometry has significant implications in theoretical physics. This narrative will extend as we delve into the theory of Topological Geometrodynamics and its unique approach to geometrization. As the conversation progresses through the subsequent interview, we will touch upon an even more ambitious unification effort to merge classical and quantum physics, number theory, and potentially even cognition.

Part II: Interview

Transitioning from a historical overview of mathematics and physics in our scope, we now focus on the central subject of this essay: the early history and core concepts of Topological Geometrodynamics. This theoretical framework aims to unify all physical phenomena from a geometric perspective. The driving force behind TGD's unification goal is Doctor Matti Juhani Pitkänen.

Born in 1950 in Kiuruvesi, a small Finnish city known for its ecological agriculture, Dr. Pitkänen began exploring theoretical physics and mathematics at Helsinki University in 1970. Seven years into his academic career, the concept of TGD emerged in the late 1970s. "The seed idea of TGD materialized in October 1977, and I proposed it as the subject of my doctoral research in the early 1980s. Initially, the concept was called geometroelectrodynamics," Dr. Pitkänen recounts. "These nascent ideas evolved into my Ph.D. at Helsinki University in 1982. At this time, the name transitioned to Topological Geometrodynamics because the framework was about gravity and electrodynamics and included a broader unification of matter. Wheeler suggested the final name in his referee statement. The core principles I introduced then remain the cornerstone of TGD today."

Professor Jouko Mickelsson supervised Dr. Pitkänen's doctoral research at the University of Jyväskylä. He also recalls meaningful interactions with Raimo Keskinen, a popular science educator at Helsinki University. "Rami, as we affectionately called him, was a respected figure in our academic community. Our dialogues significantly influenced my academic journey," Dr. Pitkänen shares.

Wheelerian Roots

The International Journal of Theoretical Physics (IJTP) featured a series of Dr. Pitkänen’s research papers on Topological Geometrodynamics from 1983 to 1992. By this point, TGD had already developed most of its foundational principles.

Pitkänen's work picks up speed from John Wheeler, known for promoting geometrodynamics in the 1960s. Wheeler explored concepts like superspace, which represents the space of all possible configurations of the three-dimensional geometry of space. Here, geometrodynamics sought to describe the universe's dynamics through the evolution of these spatial configurations, focusing on understanding the quantum aspects of gravity and the universe[6].

Wheeler introduced the idea of geons, which are gravitational wave packets confined to a compact spacetime region. These packets are maintained by the gravitational pull of the wave's field energy. Additionally, he developed the semi-unified field theory, which partially integrates gravitation and electromagnetism.

Wheeler introduced ideas like ‘mass without mass,’ ‘charge without charge,’ and ‘field without field.’ He hypothesized that spacetime might display a foam-like structure on microscopic scales, resulting in the emergence of complex topological phenomena. "I reshaped the term ‘quantization without quantization’ following his rhetoric," Dr. Pitkänen details.

Furthermore, Wheeler suggested a symmetry between magnetic and electric fields, theorizing that electric field lines ending on an electron's surface might extend through a minuscule wormhole and terminate on a positron in a separate, remote spacetime region[7]. Wheeler also contributed significantly to studying black holes, coining their name for the rest of us, and proposed the 'it from bit' concept, which connects physics with information theory.

"Wheeler's thought-provoking ideas impacted me as a theoretical physicist," Dr. Pitkänen says. "Wheeler's very positive referee statement about my 1982 article, which subsequently formed the basis of my thesis, encouraged me to continue my work. I am

[6] This initiative gave birth to the initial value formulation of GR, also known as ADM formalism, an acronym derived from the names of its creators, American physicists Richard Arnowitt, Stanley Deser, and Charles Misner. ADM formalism reconceptualizes spacetimes as spatial hyperslices and reframes the vacuum Einstein field equation as an evolution equation. This methodology outlines how the geometry of an initial hyperslice progresses over 'time.'

[7] Charles Misner, Kip Thorne, and Wojciech Zurek, John Wheeler, relativity, and quantum information, April 2009 (caltech.edu)

still wondering how I found the IJTP journal, where David Finkelstein, an emeritus professor of physics at the Georgia Institute of Technology, was an editor. Finkelstein accepted my work and, being in contact with Wheeler, helped everything fall into place. Wheeler's intervention was a big surprise. My theory was taken seriously and was accepted as a dissertation."

However, Dr. Pitkänen expresses regret over a puzzling incident that occurred after he applied for a docentship at the university in the 1990s. It involved a referee statement that gave the impression that his ideas were mentally unsound.

Another unfortunate incident happened at that time. "To my dismay, those intricately handwritten papers of Wheeler circulating in the University of Helsinki and a stack of other research material were inexplicably removed from my university office closets," he laments. What happened remains a mystery.

Seeds from Global Energy Problem of General Relativity

The inception of TGD was triggered by Dr. Pitkänen's desire to tackle the unresolved issue of global energy conservation in GR. While examining this question, he discovered a way to integrate elements from the Standard Model, quantum theory, and gravity.

"My original aim was to develop a new approach to the so-called energy problem in general relativity, which most people did not consider an issue then. Even today, the discourse around it remains relatively muted, supposing that the issue was solved at the early age of general relativity. In my opinion, the root issue remained unresolved despite attempts to introduce new kinds of pseudotensors, as pursued by Einstein and many others later. During this investigation, I recognized the potential for a broader discovery," Dr. Pitkänen explains the origins of TGD.

Dr. Pitkänen further elaborates on the energy problem: "In the general theory of relativity, spacetime is a metric deformation of Minkowski space, denoted by M^4. While M^4 is flat, representing an empty spacetime as in the special theory of relativity, its deformation makes it curved. GR's fundamental premise states that matter warps spacetime, a relationship mathematically formulated by Einstein's equations. However, symmetries of flat M^4, specifically Poincaré invariance, are lost upon deformation. According to Noether's theorem, each lost symmetry correlates with a broken conservation law. In this context, deformation affects energy and momentum conservation, making it a seeming issue in curved spacetime compared to flat spacetime."

Dr. Pitkänen describes the concept of Poincaré invariance, encompassing translations and Lorentz transformations, as fundamental symmetries in defining classical physics laws. However, in GR, specifically within curved spacetime, maintaining Poincaré symmetries becomes unfeasible. This limitation arises because the variational principle in GR's modern formulation does not intrinsically guarantee the preservation of these symmetries but concentrates on preserving general coordinate invariance instead.

Variational Principle

There is much to unpack, so let us first recall the variation method for defining field equations. The variational principle states that the path a physical system takes between two states is the one for which a certain quantity, known as the action, is stationary, usually a minimum or maximum. In the original Euler and Lagrange formulation of the variational method, time was the only independent variable in the action. The variation was tied to the principle of least action, or stationary action point, as we also call it nowadays.

In GR, the action considered is the Einstein-Hilbert action, S_{EH}, with several independent variables. S_{EH} is computed by integrating the Ricci scalar R, the Lagrangian[8] density for matter L_m, and the determinant $\sqrt{-g}$ of the metric tensor $g_{\mu\nu}$ over four-dimensional spacetime, symbolized as d^4x.

By naming convention, when the Greek letters mu (μ) and nu (ν) are used in the GR equations, they specifically refer to indices 1 to 4 with Minkowskian signature, in which the diagonal of the metric tensor matrix is mostly positive (-, +, +, +), or

[8] Instead of forces, Lagrangian mechanics uses the energies in the system. The central quantity of Lagrangian mechanics is the Lagrangian, a function that summarizes the entire system's dynamics. Overall, the Lagrangian has units of energy, but no single expression for all physical systems. - Lagrangian mechanics (wikipedia.org)

alternatively, mostly negative (+, -, -, -)[9], where one component is time, and the other three are spatial dimensions. Such a generic metric tensor $\eta_{\mu\nu}$ can be represented as a matrix:

$$\eta_{\mu\nu} = \begin{matrix} \mathbf{-1} & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & \mathbf{1} \end{matrix}$$

If Latin letters m and n were used instead, the supposed space metric would be Euclidean with (+, +, +, +) diagonal. The term d^4x combined with $\sqrt{-g}$, acts as the integration measure, where d^4x represents differential spacetime's infinitesimal volume element in the integral. g can be considered a factor that scales complex volumes in a curved spacetime relative to simpler volumes in flat Euclidean or Minkowskian spacetime and ensures that the volume element is correctly transformed under coordinate changes. Mathematically, as a whole, Einstein-Hilbert action is expressed as:

$$S_{EH} = \int (R + L_m)\sqrt{-g}\, d^4x \ .$$

The variational principle states that the actual evolution of a system between two configurations is such that the action S_{EH} is stationary, i.e., it does not vary with respect to slight variations in the metric tensor $g_{\mu\nu}$. The process involves calculating the variation of the action and setting it to zero to find the equations the metric tensor must satisfy. Mathematically, this is expressed as $\delta S_{EH} = 0$, where δ represents a small variation induced by a small metric variation. This condition leads to the Einstein field equations.

The Einstein-Hilbert action is defined by its invariance under diffeomorphisms, also known as general coordinate invariance or tensor general covariance. This property aligns with a) Einstein's strong equivalence principle, asserting that physics

[9] Professor Cliff Burgess explains that on the West Coast of the US, in particle physics, the mostly negative notation was used. Still, he thinks one reason pro mostly positive metric comes from the infinite temperature field theories where Wick rotations or transformations from Minkowski to Euclidean space become easier. See the interview by Hassaan Saleem Phymaths podcast # 38 || Dr. Cliff Burgess, 7 January 2024, 9:05 (youtube.com)

laws are consistent in inertial and gravitational accelerating frames—the original concept in Einstein's gravity theory, and b) the pre-Einsteinian weak equivalence principle, which asserts that all objects with mass follow the same geodesics; a light feather and a heavy cannonball fall at the same rate in free fall.

Terms of the Einstein-Hilbert Action S_{EH}

Term	Symbol	Description
Ricci Scalar	R	A scalar quantity representing the curvature of spacetime derived from the Ricci tensor.
Lagrangian Density for Matter	L_m	Represents the matter's contribution to the total action.
Metric Tensor Determinant	$\sqrt{-g}$	The square root of the negative determinant of the metric tensor $g_{\mu\nu}$, integral in defining volume elements in curved spacetime.
Integration Measure	d^4x	Represents the four-dimensional volume element over which the action is integrated.
S_{EH} Formula	$\int (R + L_m)\sqrt{-g}\, d^4x$	The action is calculated by integrating the sum of the Ricci scalar and the Lagrangian density for matter, multiplied by the metric tensor determinant over the four-dimensional spacetime.
Variation of the Action	$\delta S_{EH} = 0$	When δS_{EH} is set to zero, the variations are calculated, and the result is a set of differential equations that the metric tensor must satisfy, i.e., the Einstein Field Equations.

In GR, curved spacetimes are characterized by more complex metrics than the flat spacetime metric. While some curved spacetimes, like the Schwarzschild metric for spherically symmetric fields and the Kerr metric for rotating bodies, do exhibit symmetries that allow for certain conserved quantities akin to Poincaré symmetries, these symmetries are not as comprehensive as those in flat spacetime. For example, the Schwarzschild metric has a time translation symmetry and a spherical symmetry, and the Kerr metric has a time translation symmetry and an axial symmetry.

In more general curved spacetimes, like those described, e.g., by the Friedmann-Lemaître-Robertson-Walker metric used in cosmology, symmetries are fewer or even nonexistent. The FLRW metric, represented as a diagonal matrix

$(-1, a(t)^2, a(t)^2 r^2, a(t)^2 r^2 sin^2\theta)$ with r and θ as spatial coordinates and $a(t)$ as the time-dependent scale factor illustrates a spacetime that expands over time. In this scenario, traditional Poincaré symmetries do not apply at all.

In flat, homogeneous, and isotropic spacetime, as seen in Minkowski space and found consistent with SR, the metric takes a simple diagonal form in Cartesian coordinates with components (-1, 1, 1, 1). These symmetries in flat spacetime are essential for conserving lengths, areas, and volumes. However, the metric tensor cannot be universally simplified to Minkowski space to represent all curvature forms in curved spacetimes. This inherent complexity of curvature forms contrasts the uniformity of flat Minkowski space in which the global Poincaré symmetries are held.

Einstein Field Equations

Here, we present only the basic forms and components of the equations so that the context becomes apparent and the reader can find more information from the textbooks. The main mathematical tool required to work with the variational principle and Einstein field equations is Ricci calculus[10].

The Einstein field equations are denoted as follows:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu} \ ,$$

often further simplified as $G_{\mu\nu} = \kappa T_{\mu\nu}$, are a cornerstone of GR. These equations have ten interrelated equations derived by varying the Einstein-Hilbert action. The Einstein field equations express how matter and energy, represented in the energy-momentum tensor $T_{\mu\nu}$, with Einstein's gravitational constant $\kappa = \frac{8\pi G}{c^4}$, determine spacetime curvature. This curvature is depicted by the Ricci tensor $R_{\mu\nu}$, the Ricci scalar R, the metric tensor $g_{\mu\nu}$ collectively forming the Einstein tensor $G_{\mu\nu}$, and the cosmological constant term $\Lambda g_{\mu\nu}$.

In his equations, Einstein introduced the cosmological constant Λ for a static universe. However, after observations by Edwin Hubble, Georges Lemaître, and others

[10] Ricci calculus (wikipedia.org)

at the turn of the 1920s and 30s indicated that the universe was expanding, Einstein labeled the introduction of Λ as his 'biggest blunder' because observations were contrary to his additional term in GR. In contemporary cosmology, the cosmological constant has found relevance again. It contributes to the energy density of empty (vacuum) space, or hypothetical dark energy, accelerating the universe's expansion.

The Ricci scalar, derived from the Ricci tensor, which in turn is contracted from the Riemann rank-4 tensor $R^{\rho}_{\sigma\mu\nu}$, defines spacetime geometry comprehensively. The Riemann tensor is based on the connection coefficients or Christoffel symbols $\Gamma^{\rho}_{\mu\nu}$, functions of the metric tensor and its first derivatives, which constitute the components of the Levi-Civita connection[11] when considering the metric tensor and its derivatives. The Riemann tensor is represented as:

$$R^{\rho}_{\sigma\mu\nu} = \partial_{\mu}\Gamma^{\rho}_{\nu\sigma} - \partial_{\nu}\Gamma^{\rho}_{\mu\sigma} + \Gamma^{\rho}_{\mu\lambda}\Gamma^{\lambda}_{\nu\sigma} - \Gamma^{\rho}_{\nu\lambda}\Gamma^{\lambda}_{\mu\sigma} \,,$$

which is one of the demanding equations in GR, often causing mistyping indices when solved manually. The Einstein Toolkit[12], SageManifolds[13], MapleSoft[14], Wolfram Mathematica Ricci package[15], and SciPy[16] provide a programmatic way of dealing with time-consuming and error-prone calculations nowadays.

Relevant to the conservation law problem, there are infinitely many other coordinate systems where Christoffel symbols do not vanish. Inertial forces like centrifugal and Coriolis forces can be observed in these coordinate systems. These forces are perceived due to the choice of coordinates. Gravity, too, can locally be thought of as a coordinate force, which relates to the strong equivalence principle. In a spacetime region that is small enough, gravity's effects can be transformed away by

[11] Levi-Civita connection, defined in the context of a Riemannian manifold, is torsion-free and metric-compatible. This connection describes how vectors are parallel transported on the manifold, ensuring that the geometry defined by the metric tensor is consistently applied across the spacetime fabric. It defines the geodesics of the manifold, which represent the paths that particles follow when moving under the influence of gravity alone, with no other forces acting upon them.

[12] The Einstein Toolkit (einsteintoolkit.org)

[13] SageManifolds (sagemanifolds.obspm.fr)

[14] Overview of General Relativity Computations (maplesoft.com)

[15] Ricci: A Mathematica package for doing tensor calculations in differential geometry (sites.math.washington.edu)

[16] SciPy (scipy.org)

choosing the correct coordinate system, just like how coordinate forces can appear or disappear depending on your point of view.

Furthermore, general coordinate invariance is passive in nature. Changing the labels or names of objects (like particles 1, 2, 3 to a, b, c) does not affect the physical system's behavior. It is like agreeing that renaming cities on a map does not change their actual locations or distances from each other. In contrast, active symmetry would involve physically moving or altering the system itself, not just relabeling parts of it.

Multiplying the Ricci scalar with the metric tensor $g_{\mu\nu}$ and subtracting it from the Ricci tensor results in the Einstein tensor having zero divergences in the field equations. This mathematical formulation results in the vanishing covariant divergence condition of the contravariant tensor $\nabla_\mu T^{\mu\nu} = 0$, implying the approximate local energy and momentum conservation in GR.

The notion of spacetime being flat and symmetric holds only in infinitesimally small regions, akin to Minkowski space in special relativity. This mathematical treatment allows us to apply local conservation laws like those in flat spacetime. However, in practical scenarios where we consider finite regions of spacetime, this denotation becomes less precise, so we can argue that even the local conservation is only approximate.

Dr. Pitkänen states, "As long as a non-vanishing Ricci scalar tensor determines the curvature, the Poincare symmetries are lost, causing the loss of the global conservation laws according to the Noether theorem."

However, based on the historical records, it seems that Einstein, Hilbert, and Klein were satisfied with Noether's theorems' conclusion that the classical energy conservation in SR and the definition of conservation laws in GR differ like day and night. In the next section, I will outline the historical context and initial discussions surrounding the energy problem and conservation laws as they were first contemplated in the early days of GR. After that, we will shift the discussion to examining how TGD addresses and possibly resolves these complex and enduring challenges, advancing the quest for unification.

Terms of the Einstein Field Equations (EFE)

Term	Symbol	Description
Riemann Tensor	$R^{\rho}_{\sigma\mu\nu}$	Represents the curvature of spacetime. It quantifies how the parallel transport of a vector around an infinitesimal loop fails to return it to its original direction. This tensor encompasses information about tidal forces and the bending of geodesics in spacetime.
Ricci Tensor	$R_{\mu\nu}$	Describes how much spacetime is curved at a particular point, obtained by contracting the 4-rank Riemann tensor, which in four-dimensional spacetime has 20 independent components (from 256 total), to a symmetric 2-rank tensor with ten independent components.
Ricci Scalar	R	Scalar value representing the curvature derived from the Ricci Tensor.
Metric Tensor	$g_{\mu\nu}$	Describes the geometry of spacetime, including distances and angles.
Einstein Tensor	$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu}$	Combines Ricci Tensor and Scalar. Automatically satisfies the condition of having zero divergence in $G_{\mu\nu}$, which also reflects into the energy-momentum tensor side of the field equations.
Stress-Energy-Momentum Tensor	$T_{\mu\nu}$	A rank-2 tensor representing the distribution and flow of energy and momentum in spacetime. In four-dimensional spacetime, it has 16 components, but due to its symmetry, only 10 are independent.
Cosmological Constant	$\Lambda g_{\mu\nu}$	Represents the energy density of space related to the metric tensor, accounting for the universe's accelerated expansion.
Einstein's Gravitational Constant	κ	A constant $\kappa = 8\pi G/c^4$ relating the geometry of spacetime to the energy and momentum within it.
EFE Formula	$G_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$	The equation asserts that the curvature of spacetime is directly proportional to the energy and momentum at each point in spacetime with the cosmological constant term.

Covariant Divergence	$\nabla_\mu T^{\mu\nu} = 0$	The condition signifies that energy and momentum are conserved locally in GR. "Locally" means that energy and momentum are not spontaneously created or destroyed in any infinitesimally small volume of spacetime.

Noether's Theorems and Symmetries

Geometric operations like translations and rotations correspond to certain conservation laws in Noether's theorems. Einstein addressed these principles in the supplementary material published in 1916, aiming to clarify questions about energy conservation in GR and the gravitational field especially. For the next couple of years, the discussion on the issue of conservation laws in SR and GR was dense.

Emmy Noether, a notable German woman mathematician, worked with Hilbert and Klein to prove how conservation laws for general relativity differ from classical mechanics and SR through her two theorems published in 1918[17]. At that time, Noether was renowned for her invariance and group theories expertise. Hilbert and Klein constantly consulted Noether with the subject's intricacies and left the final word, proving the theorems, in her hands, which she did between 1915 and 1918[18].

The first theorem deals with symmetries described by *finite* continuous groups, also known as Lie groups, which are determined by a finite number of parameters. The theorem states that there is a corresponding conservation law for every independent continuous symmetry of the action, the integral of the Lagrangian over time. For example, invariance under time translation leads to energy conservation, and invariance under spatial translation leads to the conservation of linear momentum. Noether's first theorem leads to the familiar conservation laws in classical mechanics and SR settings, where the symmetries are related to the spacetime structure, like time

[17] Emmy Noether, Invariante Variationsprobleme (1918)
[18] David Rowe, Emmy Noether on Energy Conservation in General Relativity (2019)

translations, spatial translations, and rotations. The Killing vector fields ξ^{μ} can be used to prove spacetime symmetries in mathematical rigor[19].

Noether's second theorem concerns invariant variational principles under transformations described by *infinite* continuous groups determined by functions and their derivatives. If a system is invariant under an infinite group, the Lagrangian expressions are not independent but satisfy certain identities. In GR, the infinite group in question is the group of general coordinate transformations, which reflect the general covariance of GR. Noether showed that such invariance leads to identities, now known as Noether identities, that the field equations must satisfy. That implies that the conservation laws in GR, arising from its invariance under arbitrary coordinate transformations, are different than those in theories with finite symmetries. GR conservation laws are notably referred to as improper by Noether.

An interesting period of history occurs after the publication of the theorems. They were practically forgotten for decades. Although Noether was celebrated as one of the great female mathematicians of the known era in her funeral memorials in 1935, Noether's contribution was recognized only from the algebra side of mathematics. After the publication, she did not return to the variational invariance theorems and referred to them only cursorily a few times. Nor did other physicists until the 50s and 60s. When researchers independently formulated symmetry and conservation laws related to QFT, Noether was still not much referred to. Only in the 70s did she get recognition with growing references and citations, and the case of conservation laws and symmetries in physics and the grand scheme of unification programs started to emerge.

French mathematician and professor Yvette Kosmann-Schwarzbach has written extensively about this topic in her book "The Noether Theorems - Invariance and Conservation Laws in the Twentieth Century." She also provides some speculations on how and why this happened. That Noether was a Jewish woman and worked as an employee under Klein's program—the prevailing scientific norms and biases of the time—might have caused the diminishing, but it does not entirely explain the case. Noether later worked in a respected position in a renowned mathematics department in Gottingen, central Germany.

[19] See Appendix 4 for more information about Killing vector fields.

Contemporaries probably regarded GR as such a huge step from SR and earlier classical physics that they accepted that conservation laws do not behave the same way in GR. Many references to Noether did not acknowledge the two separate theorems, and their relation indicated that the full conjecture was unclear for many. The theorems were highly abstract and not immediately connected to the practical problems physicists were tackling at the time, other than relativity.

Noether's last statements in her theorem paper reflect the difficulty of taking a position[20]:

> "As Hilbert expresses his assertion, the lack of a proper law of energy constitutes a characteristic of the 'general theory of relativity.' For that assertion to be literally valid, it is necessary to understand the term 'general relativity' in a wider sense than is usual, and to extend it to the aforementioned groups that depend on n arbitrary functions."

As if the issue occurs only when GR is derived from the variational principle, analyzed through the lens of group theory, and demanded to hold Poincaré symmetries, only then is there a problem, and Hilbert is right in his 'characteristic' take on GR.

Noether calls GR conservation laws improper throughout the paper but then draws back the case in the last statement. It is a bit puzzling and incoherent but can be explained so that the group theoretical justifications for conservation laws in SR and GR were not established then. In the early formulation, one could not take such strong opposition because Einstein built his theory from intuitions involving considerable trial and error. He evaluated various forms of the field equations until he found one that satisfied all physical and mathematical requirements.

In some sense, Dr. Pitkänen's work goes along with the historical line of raising interest and acknowledging Noether's work in the 1970s. It is part of the scientific process that researchers find things independently and recurring. Only later do we have all the published documents available, where we can see the parallel development of the ideas in a bigger picture.

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[20] Translation from Yvette Kosmann-Schwarzbach, The Noether Theorems - Invariance and Conservation Laws in the Twentieth Century, p.22 (2011)

Conceptual Challenges of Conservation Laws in General Relativity

Defining global conservation in GR is complicated due to the absence of a fixed, global reference frame. The notion of energy and its conservation becomes complex in an expanding universe[21] or black holes with unclear boundaries. Theoretical questions arise: How does global energy behave in an expanding universe or spacetimes characterized by gravitational waves or black holes? Can the gravitational field be conceptualized as interacting with other forces in a way that allows for a comprehensive energy accounting? This also ties the problem into the broader quest for a unified theory reconciling GR with quantum mechanics.

In his 1983 article "On the Energy Problem in General Relativity," Alexander Poltorak highlights the main challenges in this domain:

A. The absence of a covariant, unique, and conservative energy-momentum tensor for the gravitational field within the GR framework. This issue underscores the difficulty in defining a universal measure of energy in a theory where spacetime itself is dynamic and curved.
B. The inherent challenge in obtaining global integral invariant quantities for asymmetric fields. Even if a suitable energy-momentum tensor existed, the asymmetry of realistic gravitational fields in the universe complicates establishing global conservation laws.
C. The lack of a precise reference frame definition in GR adds to the difficulty in formulating consistent conservation laws. This issue reflects the relative nature of spacetime and motion in Einstein's theory. Similarly to how time dilation occurs across various frames of reference, energy measurements can vary when observed from different coordinate systems.
D. The limitations of the Lagrange formalism commonly employed in GR may need to be more rigorous to address the intricacies of energy conservation in curved spacetime. Limitations include GR's inherent nonlinearity, the lack of global symmetries, the dependence on reference frames, difficulties with asymptotic conditions, and issues with energy localization.

[21] Strange but true: the expanding Universe doesn't conserve energy, 2 May 2023 (bigthink.com)

The issue of energy conservation in GR is often understated or described as 'subtle' or 'nuanced,' a perspective shared by theoretical physicists like Sean Carroll[22]. Pre-trained language models, such as ChatGPT[23], phrase the issue similarly.

Furthermore, recent discussions and arguments to validate classical GR energy conservation approaches often rely on tensorial manipulations, pseudotensors[24], adding something new to the geometric structure of GR, or the generalization of Noether's theorems[25] [26] [27]. These approaches highlight the need to extend or modify the standard formulation of GR to reconcile it with the concept of global conservation laws. Ongoing debates and explorations in the field indicate that the question of energy conservation in GR remains an unsettled area of research in theoretical physics. One could also see these dilemmas as a steppingstone to addressing further issues on the unification of physics, as did Dr. Pitkänen.

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[22] Sean Carroll, The Biggest Ideas in the Universe: Space, Time, and Motion, p.25 (2022)
[23] Global Energy Conservation in GR - ChatGPT Conversation (chat.openai.com)
[24] See Appendix 5 for more information about pseudotensors.
[25] Philip Gibbs, Energy Is Conserved in the Classical Theory of General Relativity (2010)
[26] Sebastian De Haro, Noether's Theorems and Energy in General Relativity (2021)
[27] Stefan Ruster, Energy is Conserved in General Relativity (2022)

Poincaré Invariance, Noether's Theorem, and Flat vs. Curved Spacetime

Aspect	**Flat Spacetime (M^4) and SR**	**Curved Spacetime (GR)**
Symmetries	Full Poincaré invariance (translations and Lorentz transformations)	Limited or absent Poincaré symmetries; specific symmetries for certain metrics
Conservation Laws	Energy and momentum conserved (due to Noether's theorem in SR context)	Energy and momentum conservation issues (breaking of Noether's conservation laws in GR)
Geometry	Homogeneous and isotropic (consistent with SR principles)	Varies (e.g., Schwarzschild, Kerr, FLRW metrics)
General Coordinate Invariance (GCI)	Applicable also in SR (inertial frames are in a special position since the spacetime is flat)	Fundamental in GR; Einstein's equations are generally covariant
Lorentz Invariance	Fundamental in SR; consistent throughout Minkowski space	In curved spacetime (GR), local Lorentz invariance can be defined as approximate symmetry, but global invariance is lost
Noether's Theorem	Symmetries in SR lead to conservation laws (energy, momentum, angular momentum, etc.)	Loss of symmetries in GR leads to the breaking of corresponding conservation laws, and the conserved quantities are not even defined except in flat space approximation
Framework	SR is a theory defined in flat spacetime, with inertial frames in preferred position, but where general coordinate invariance is valid also	GR generalizes SR to include curved spacetimes

Resolution to Energy Problem - Short Answer

How does one resolve the difficulty of conserving global conservation laws in TGD, then? Dr. Pitkänen elucidates, “The core idea is a change of perspective from the symmetries acting in GR spacetime to the imbedding space symmetries and affecting the spacetime surface as a whole. Symmetries affect the spacetime surface similarly to how rotations and translations affect rigid bodies. The entire spacetime surface is rotated and translated rather than points in ordinary GR. One identifies 4-D spacetimes as 4-surfaces interpreted as orbits of 3-D particles in some higher-dimensional spacetime $H = M^4 \times S$ so that the symmetries of M^4 and space S are symmetries of the theory. Therefore, classical conservation laws are not lost. The solution is straightforward. We just have to find unambiguous and unique arguments to select some space S, which could also explain the conservation laws assignable to the Standard Model symmetries.”

This elucidation requires a deeper inspection to be comparable to our original energy conservation issue. Let us start by defining spacetime and action and see how all works out in TGD.

Imbedding Hyperspace

The intellectual roots of TGD are firmly planted in the bedrock of modern theoretical physics. However, the initial setup for physics is unique and differs from string models or any other unification theory.

"TGD pivots around the 8-dimensional hyperspace H, a Cartesian product of Minkowski space M^4 and a complex projective 2-space CP_2[28]. The equation or rather a form $M^4 \times CP_2$ is the central expression in TGD," Dr. Pitkänen typically begins his explanation. That is to say, the choice of $H = M^4 \times CP_2$ as the imbedding space is one of the main starting points and serves as a mnemonic equation for TGD.

According to TGD, the classical universe is a fractal hierarchy of spacetime surfaces of various sizes. Dr. Pitkänen likens the higher-dimensional static

[28] By a naming convention, 4 in M^4 refers to dimensions, not to the power of M. Similarly, 2 in CP_2 refers to dimensions. In the context of general relativity super and sub script components usually refer to tensor indices or space dimensions.

background hyperspace to a fundamental platform where all spacetime surfaces reside. The surface comes from the preferred extremal solutions of the action functional, and it is like a thin glass plate if some mundane visualization is sought. It holds inside spacetime sheets interconnected with wormholes at the incredibly tiny CP_2 length, roughly 10^4 Planck scales.

"The static backdrop, hyperspace H metric, and other geometric properties are projected, or induced, as I term it, onto a tangent vector field of the dynamic 3-dimensional surface in motion, referred to as X^4 since it moves in the time dimension. Via the induction process, X^4 gets embedded to H," Dr. Pitkänen expounds.

After a small breath break, Dr. Pitkänen continues, "In my early work, I proposed X^3 as a fundamental object. A further investigation led to the understanding that the particle as a 3-D surface must be replaced by its 4-dimensional orbit in hyperspace, which by holography is almost unique and could, therefore, be called 'Bohr orbit'. A particle is understood in a general sense. Any 3-surface with a finite size is a particle. They are basically the same notion."

Actions and Field Equations in TGD

Initially, the term 'higher-dimensional surface' might seem like a strange nomenclature. However, for mathematicians, dealing with dimensions of various shapes is routine. The process begins with visual representations in lower dimensions. Mathematicians identify mathematical forms for these dimensional objects and add dimensions incrementally to their equations. Although visual interpretations become less apparent at higher dimensions, the expansion into these realms is facilitated using mathematical methods, concepts, and symbols.

The emergence of physical dynamics on surfaces in the space of 3-surfaces is not random but governed by a variational principle and hyperspace H structures. In contrast to classical general relativity, which assumes a sole unique spacetime manifold, quantum theory necessitates the consideration of quantum superposition of spacetime surfaces. TGD has this feature built-in because the solutions of the TGD action variation yield many-sheeted spacetime.

Identification of the Lagrangian, deduction of field equations stating that the action does not change for slight variations, and deduction of the Lagrangian symmetries implying the conservation laws by using Noether's theorem is a usual procedure for motivating field and motion equations in modern physics, as presented earlier. The difference is that Poincare symmetries are not symmetries of the action in the traditional GR formulation, whereas they are in TGD.

"Could I formulate a truly general coordinate invariant theory for GR?" Dr. Pitkänen asks himself. "Initially, I played with the Einstein-Yang-Mills action, but I found it unsatisfactory. The subsequent trial was Kähler's action as an analog of Maxwell's action, but it also had some problems, such as the huge vacuum degeneracy. Finally, the 'twistor lift' of TGD led to the addition of the volume term, which has an interpretation in terms of the cosmological constant to the Kähler action."

The Einstein-Yang-Mills action effectively merges two fundamental theories in physics: general relativity and gauge theory. The Einstein-Hilbert action uses the spacetime metric to show how spacetime is curved by matter and energy. On the other hand, the Yang-Mills action extends the principles of gauge theory beyond electromagnetism, as described by the Maxwell action. While the Maxwell action deals with Abelian gauge theories, specifically the $U(1)$ gauge group for electromagnetism, the Yang-Mills action generalizes this to non-Abelian gauge theories, encompassing the $SU(2)$ and $SU(3)$ gauge groups responsible for the weak and strong nuclear forces, respectively.

In TGD, a lot is encoded in Kähler and spinor structures. The Kähler structure, named after Swedish mathematician Erich Kähler, is a special geometric entity combining different geometric characteristics like shape, size, and orientation. Dr. Pitkänen continues, "One might say that the Kähler manifold generalizes the notion of a complex plane. Its application in TGD is unique—the induced Kähler form of CP_2 defines the $U(1)$ part of the electroweak gauge field. Also, M^4 allows the analog of the Kähler structure, and the twistor lift of TGD forces it to be considered[29]. The essential point is that M^4 also has a Kähler structure or its analogy where the tangent space of M^4 is extended to M^2 and E^2. E^2 has a conventional Kähler structure, thus a complex structure. M^2 has a hypercomplex structure (the square of the imaginary unit equivalent is 1 and not -1) associated with an analog of the Kähler structure. The complex coordinate $x = x + iy$ and its conjugate $x - iy$ are replaced by light-like coordinates $t + z$ and its hypercomplex conjugate $t - z$. This was not at all obvious

[29] Nigel Hitchin, Kählerian Twistor Spaces (1981)

initially, and for a long time, it was assumed that only CP_2 was associated with Kähler geometry and that the Kähler structure of M^4 breaks Poincare and Lorentz invariance."

In TGD, the motivation for focusing on the induced Kähler form arises from its role in defining an analog to the Maxwell field. In this context, the induced Kähler form on the spacetime surface serves a similar function to the electromagnetic field in Maxwell's theory[30].

TGD Action

The action in TGD, denoted as S_{TGD}, is a sum of two terms: the Kähler action S_K and the volume action S_V. It is given by the integral of the TGD Lagrangian density L_{TGD} over four-dimensional spacetime coordinates:

$$S_{TGD} = S_K + S_V = \int L_{TGD} d^4x = \int L_K d^4x + \int L_V d^4x \ .$$

The Kähler action is derived similarly to the Maxwell action, but TGD replaces the Maxwell field with the *induced* Kähler field. The Kähler action S_K is constructed by Kähler Lagrangian density L_K as:

$$L_K = \frac{1}{2\alpha_K} \int J^{\mu\nu} J_{\mu\nu} \sqrt{-g} \ .$$

Here, a Kähler form J is a specific antisymmetric type of two-form, i.e., $J^{\mu\nu} = -J^{\nu\mu}$. The indices μ and ν refer to the spacetime dimensions. $J^{\mu\nu}J_{\mu\nu}$ represents the *induced* Kähler field, where the product of contravariant $J^{\mu\nu}$ and covariant $J_{\mu\nu}$ fields ensure that the action is invariant under coordinate transformations.

g is the determinant of the *induced* metric tensor $g_{\alpha\beta}$ on the spacetime surface. The square root of the negative determinant is a standard component in action integrals in general relativity and related theories, ensuring the correct volume element for integration over spacetime. α_K is the sole coupling constant in TGD, which

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[30] Conversely, in theories like supergravity and supersymmetric field theories, the Kähler action is formulated on the field space of scalar fields as a Kähler manifold, which leverages their unique Hermitian metric properties.

sets the strength of the interaction or coupling in theory. Quantum criticality conditions determine its discrete spectrum. α_K is also related to number theoretic coupling constant evolution in TGD[31].

The induced metric $g_{\alpha\beta}$ and the induced Kähler metric $J_{\alpha\beta}$ are linked to symmetries and conservation laws. $g_{\alpha\beta}$ is expressed as tensor projections of the imbedding hyperspace H metric by:

$$g_{\alpha\beta} = h_{kl}\partial_\alpha h^k \partial_\beta h^l ,$$

where α, β are indices on X^4, and k, l are indices in H. The partial derivative functions $\partial_\alpha h^k$ and $\partial_\beta h^l$ represent the components of the tangent vectors at a point on of X^4, and h_{kl} is the metric tensor of H. The coordinates h^k of H as functions of the spacetime coordinates X^α specify the spacetime surface.

The induced Kähler metric $J_{\alpha\beta}$ is expressed by:

$$J_{\alpha\beta} = J_{kl}\partial_\alpha h^k \partial_\beta h^l .$$

h^k and h^l are the primary dynamical variables in terms of which g and J are expressed.

Variation of the action and field equations are with respect to h^k. We are looking for a surface where the change in action at the first order vanishes ($\delta^1 S = 0$) for any variation δh^k. This connects the symmetries of H as isometries to the X^4 tangent space by induction. Transformations, on the other hand, concerns spacetime as a whole rather than a point in it. Now, **since we have projected isometries on the dynamics of spacetime, we can conclude that the classical laws are fully conserved according to Noether's theorems in TGD**—not only for M^4 spacetime, but all spacetimes, including CP_2 component satisfying the maximum and minimum of the action, or preferred extremals, as Dr. Pitkänen usually refers to it.

The volume action S_V Lagrangian density L_V in L_{TGD} is $k\sqrt{-g}$, which functions as a cosmological constant term and is essentially the volume of the spacetime surface

[31] I have deliberately tried to avoid number theoretical connections in my exploration of TGD in this essay because it would require a whole new introduction to number theory and its application in physics. For α_K coupling constant see Matti Pitkänen, Questions about coupling constant evolution, 2021 (researchgate.net), and TGD View about Coupling Constant Evolution, 2019 (tgdtheory.fi).

in the *induced* metric. This becomes dynamic in the 'twistor lift' through a process akin to a dimensional reduction, which occurs in the 12-dimensional twistor space of H. The requirement that the 6-surface be induced in the twistor space implies it is a S^2 bundle over a 4-dimensional spacetime surface. This reduction is not unique, leading to a multitude of solutions. Here, the volume term, corresponding to the S^2 degrees of freedom, becomes proportional to a coefficient akin to the cosmological constant, which varies dynamically depending on the solution. This scenario is similar to the Higgs mechanism, where the cosmological constant is analogous to the vacuum expectation value of the Higgs field. This solves the notorious problem of huge cosmological constant in many unification attempts.

Also, the topological instanton term $L_I = k\int J \wedge J d^4x$ for the TGD action is possible. It does not affect field equations in the interior of spacetime since it reduces to a total divergence transforming 3-D Chern-Simons-Kähler (C-S-K) action for the light-like partonic orbits. The contravariant induced metric is not defined for light-like surfaces, as the matrix determined by the induced metric is not invertible in these cases. Therefore, the C-S-K action, essentially a topological effect, becomes necessary for this specific dynamic context.

TGD Field Equations

The field equations for minimal surfaces[32] can be written as $g_{\alpha\beta} D_\beta \partial_\alpha h^k = 0$. These equations are satisfied for the holomorphic[33] ansatz[34] because $g_{\alpha\beta}$ is a holomorphic tensor of type (1,1), and $D_\beta \partial_\alpha h^k$ is a holomorphic tensor of type (2,0) + (0,2). This contraction vanishes since there are no common indices. The same takes place for string world sheets as minimal surfaces.

The minimal surface property in TGD leads to a geometrization of massless field equations. The concept of a 3-surface orbiting as a minimal surface generalizes the idea of a light-like geodesic line as the orbit of a particle, which is a one-dimensional minimal surface. This represents a geometrization of field-particle duality in TGD.

The Einstein-Yang-Mills equations[35] emerge only in the limit of QFT. By 4-D general coordinate invariance, there are only four independent dynamical variables. At the QFT limit, when the M^4 projection of X^4 is 4-D, they can be taken to be CP_2 coordinates.

In this limit, the concept of a many-sheeted spacetime is approximated as a slight metric deformation of Minkowski space. This approximation involves summing the induced gauge potentials from various spacetime sheets to form the effective gauge potentials. Similarly, the gravitational field is identified as a deviation from the flat Minkowski metric by summing the contributions from different spacetime sheets. Physically, this approach suggests that a small test particle interacts with all the nearby spacetime sheets, experiencing the cumulative effect of the classical forces from these different sheets. This concept is a generalization of the operational definition of

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[32] See Matti Pitkänen, Topological Geometrodynamics: Revised edition, 3 March 2016, Chapter 4.2 (books.google.fi), and What are the counterparts of Einstein's equations in TGD? 14 February 2018 (tgdtheory.fi)

[33] Holomorphism yields conserved currents for any action within the specified constraints; there also emerges an analog of a conservation law for gravitational energy. The divergence of $G^{\mu\nu}\partial_\nu h^k$ vanishes, as it reduces to contractions of holomorphic tensors of different types that vanish identically. This raises the possibility of interpreting the corresponding conserved charges in terms of gravitonic 4-momentum.

[34] An educated guess or an additional assumption made to help solve a problem and may later be verified to be part of the solution by its results. -Ansatz (wikipedia.org)

[35] Yang-Mills theory is a gauge theory that describes the behavior of the gauge fields in the Standard Model, which mediate the strong, weak, and electromagnetic interactions. The Yang-Mills equations can be written as: $D_\mu F^{\mu\nu} = J^\nu$, where $F^{\mu\nu}$ is the field strength tensor related to the gauge fields. D_μ is the covariant derivative, accounting for the gauge symmetry. J^ν represents the current associated with the gauge field, such as the color current for the strong interaction or the electric current for electromagnetism.

superposition used in Maxwell's theory, where an electric field is based on the force experienced by a test charge in the presence of an external charge distribution.

In the context of a many-sheeted spacetime, the situation is analogous. The ‘test particle’ is now an elementary CP_2 size surface, which inevitably interacts with all the sheets of the many-sheeted spacetime. It experiences the sum of the forces produced by the induced gauge fields associated with these sheets, which defines the gauge field. This same principle applies to gravity in the TGD framework.

Like string models, TGD does not yield Einstein's field equations at the fundamental level. Instead, these equations emerge only at the QFT limit. In TGD, gravitational and gauge field dynamics are geometrized into the geometrodynamics of 3-surfaces. The dynamic variables become the imbedding space coordinates $h^k(x)$, functioning as spacetime point variables, akin to the situation in string theory. This geometrization reflects a shift from traditional field-based dynamics to a focus on the geometry of the imbedding space, emphasizing the role of these coordinates in defining the physical properties and dynamics of spacetime surfaces.

This aligns with the broader theme in TGD, where classical field equations of general relativity and standard gauge theories are seen as effective, emergent phenomena rather than fundamental.

Twistorization

The concept of the 'twistor lift' of Topological Geometrodynamics, a later development in theory, is an ambitious endeavor to meld twistor theory into the TGD framework. Twistor theory, pioneered by the esteemed English mathematical physicist and Nobel laureate Sir Roger Penrose in 1967, seeks to revolutionize our approach to quantum gravity.

In physics, a twistor is a component of a two-dimensional complex vector space, and twistor space represents the collection of all twistors. The goal of twistor theory is to supersede conventional spacetime frameworks, where spinors are fundamental, with a particular twistor space. This radical replacement aims to simplify the mathematical depiction of relativistic QM.

In the formative stages of TGD, Dr. Pitkänen explored the potential of the Einstein-Yang-Mills and Kähler actions to delineate the dynamics of the theory. However, Dr. Pitkänen discovered that these methods fell short due to many issues. One notable problem with the Kähler action was the vacuum degeneracy phenomenon, the existence of a myriad of states with zero energy. This predicament created significant difficulties in defining a unique ground state for the theory.

In response to these challenges, Dr. Pitkänen conceived the 'twistor lift' of TGD. In the twistorization M^4 and CP_2 are replaced by their twistor spaces $T(M^4)$ and $T(CP_2)$ and spacetime surface X^4 with its twistor space $T(X^4)$ as a surface of $T(M^4) \times T(CP_2)$.

Emphasizing the significance of this discovery, Dr. Pitkänen adds, "The 'twistor lift' proposal offers the most straightforward choice, bringing the principle of quantum criticality to the forefront of quantum TGD. This mechanism limits the set of 4-surfaces to preferred extremals, which are minimal surfaces with lower-dimensional singularities, symbolic of the physical interactions and particles we observe. Intriguingly, the property of minimal surfaces holds for any general coordinate invariant action constructible from the induced geometry."

Mathematical Conceptual Thinking

Dr. Pitkänen frequently asks, "Am I making myself clear?" to prevent the discussion from becoming excessively complicated. Yet, despite his best efforts, he often unintentionally burrows into the intricate details of the theory. Through my interactions with him over the past years, I have realized that it is challenging to grasp the critical concepts in TGD or similar theories until you have directly seen how these concepts are represented mathematically and how they are manipulated. Once you have this foundation, understanding and discussing these theories becomes much easier and more meaningful.

We often wish to simulate and plot these ideas and structures with hand-written illustrations or computer graphics. It is impossible to visually capture the entirety of the TGD models using 3-D animations, sketches, or diagrams. Higher-dimensional representations must be expressed through mathematical formalisms and abstract, interconnected concepts. Still, developing a lower-dimensional, simplified, albeit imperfect, mental image to which you can attach and associate these concepts is helpful. Except for the eight-dimensional static hyperspace H in TGD, the three-dimensional spacetime surface in motion, in which everything practical and physical exists, is visualizable and intuitively understandable to a great extent, further than in most similar theories. Mathematical formulation may give a wrong impression in that regard. Everything interesting happens in the ordinary 4-D world, including the fourth, time, dimension in which we are used to living. Keeping this simple picture in front of the inner eyes is good practice.

Dr. Pitkänen often reminds me he is a physicist, not a mathematician. His books and articles do not contain rigorous mathematical proofs. Instead, as a theoretical physicist, he seeks to use mathematical formalisms to build a comprehensive theory based on well-established mathematical principles and physics theories. This approach may lean more towards natural philosophy, conceptual thinking, and intuition than some may be comfortable acknowledging. Yet, these concepts are firmly rooted in formal language, and each idea, no matter how whimsical it may seem without context, is based on geometric forms.

Spacetime Symmetries, Gauge Groups, and Induction

Returning to the theoretical details, Dr. Pitkänen further explains how the chosen hyperspace H helps realize the symmetries of the Standard Model, "The group theoretical symmetries of the Standard Model are geometrized in TGD because the 8-dimensional imbedding hyperspace H is obtained by replacing the points of 4-D Minkowski space M^4 with $CP_2 = \frac{SU(3)_C}{U(2)}$. CP_2 is a special unitary group 3 sliced with unitary group 2, Standard Model's strong force and electroweak gauge groups. The difference is that in the Standard Model, the continuous transformation groups are used to classify fundamental interactions, whereas in TGD, geometrical objects are the essential ingredients.

In the Standard Model, $SU(3)_C$ has an interpretation as a color group of strong interactions. $SU(3)_C$ refers to the special unitary group of degree 3, which is essentially a group of 3x3 matrices with unit determinants representing 'color' in the quantum chromodynamics (QCD) theory of strong interactions. $U(2)$ is the unitary group of degree two, representing a general phase rotation symmetry group. In TGD, the holonomy group of CP_2, $U(2)$, which is interpreted here the same as $SU(2)_L \times U(1)_Y$[36], geometrizes the electroweak symmetries. There is an essential delicacy, however. CP_2 does not allow spinor structure in the ordinary sense. Only the modified spinor structure $spin^c$ brings in the electroweak gauge group's $U(1)_Y$ factor."

Stephen Hawking, Christopher Pope, and Gary Gibbons showed in 1978-9[37] [38] that CP_2 does not allow ordinary spin structures, which are crucial for describing fermions in QFT. But later, Pope published a research paper showing that $spin^c$ structures exist in CP_2 due to the Kähler metric in it[39]. According to Dr. Pitkänen, it

[36] In the group subscripts, C represents Color, indicating the theory of strong interactions (quantum chromodynamics) among quarks. L signifies Left-handed, referring to the weak force's action on left-handed particles. Y denotes Hypercharge, a quantum number in the electroweak theory related to electric charge and weak isospin.

[37] Stephen Hawking and Christopher Pope, Generalized spin structures in quantum gravity. Physics Letters B, 73(1), p.42–44 (1978)

[38] Gary Gibbons and Stephen Hawking, Classification of Gravitational Instanton symmetries. Communications in Mathematical Physics, 66(3), p.291–310 (1979)

[39] Christopher Pope, Eigenfunctions and $spin^c$ structures in CP_2. Physics Letters B, 97(3-4), p.417–422 (1980).

was unfortunate that, at that time, no one else realized to apply CP_2 to the Minkowski spacetime and the Standard Model[40]. The potential has yet to be recognized today.

The term 'geometrization' in TGD refers to the method of expressing the group theoretical symmetries of the Standard Model in topological terms. In simpler terms, Pitkänen uses a geometric representation in the Wheelerian spirit instead of group theory to unite different fundamental interactions in the universe. CP_2 as $\frac{SU(3)_C}{U(2)}$ represents fundamental interactions in a geometrical context within the eight-dimensional hyperspace H.

In TGD, spacetime regions with 4-D M^4 projection are called spacetime sheets, which can be connected by wormhole contacts. Under a stabilizing condition, wormhole contacts build elementary particles[41]. Embedding in a vigorous sense means the sheets in hyperspace H are continuous and smooth and do not cut each other. Also, lower dimensions than four for the M^4-projection are possible, which means a deviation from GR, which is crucial for understanding the formation of astrophysical objects.

Symmetries and groups are a convenient way of talking about the Standard Model, revealing strong evidence that these symmetries form fundamental laws in nature. It is extraordinary that we can reduce fundamental forces and particles to such a mathematical structure containing symmetry-breaking configurations, gravitation, and even Higgs bosons.

In the TGD's ontological framework, there is a shift in how we understand particles. **Rather than envisioning particles as point-like or string-like entities, Dr. Pitkänen's theory envisions particles as surfaces**. "In TGD, a particle as a small 3-surface inside the extremely thin 'glass plate' defined by imbedding space H, 'experiences' all spacetime sheets by directly touching them", Dr. Pitkänen iterates.

One must notice a dimensional hierarchy, as the lower dimensional projections alluded to earlier. a) 4-surfaces as orbits of 3-surfaces, b) 3-D light-like surfaces as orbits of partonic 2-surfaces, c) string world sheets as orbits of strings, and finally, d)

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[40] Matti Pitkänen, Reduction of standard model structure to CP_2 geometry and other key ideas of TGD, 2.1.3 Spinors in CP_2 (2023)
[41] See elementary particle spectra predictions and mass calculations in TGD from Dr. Pitkänen's article Massless States and Particle Massivation, 5 January 2020 and About the Relationships Between Weak and Strong Interactions and Quantum Gravity in the TGD Universe, 5 December 2023 (tgdtheory.fi)

1-D fermion lines as the ends of string world sheets at the orbits of partonic 2-surfaces. In a well-defined sense, the string model is a sub-theory of TGD.

The induction procedure geometrizes the classical fields. Dr. Pitkänen reformulates the whole shebang, "In the induction process, we project static geometric structures of H to the spacetime surfaces. This includes the metric of H, the spinor connection of CP_2 identified in terms of electroweak gauge potentials, and the Killing vectors of color symmetries identified as color gauge potentials. Since 3-surfaces are dynamic and restricted by the variational function and mapping coordinates with the H, the induced fields are also dynamic, connected to the isometries of H, and obey conservation laws in the traditional sense. Induction gives rise to the classical fields of the Standard Model and general relativity and explains fermion fields. The symmetries of the geometry of H explain quantum numbers and particle properties. The induction also resolves the global energy definition problem of GR, which was the starting point of TGD, by lifting the symmetries from the level of spacetime to the level of H. The choice of CP_2 as some subspace S satisfied the requirement of extra structure to conserve energy or global time-like symmetry among the others. The choice is justified by previously stated Standard Model properties that CP_2 gives."

How to Add Dynamics to Theory?

Dynamics in mathematical physics studies how systems change and evolve, often governed by differential equations or dynamical systems. The mathematical foundations for understanding dynamics can be traced back to the works of Sir Isaac Newton and Gottfried Wilhelm Leibniz and further developed by mathematicians and physicists like Joseph-Louis Lagrange, William Rowan Hamilton, and Pierre-Simon Laplace.

Dynamical systems theory explores the long-term behavior of these systems, and it has applications across various branches of physics, including classical mechanics, fluid dynamics, and QM. The equations of motion describe how the state of a physical system changes with time, often using concepts from calculus and differential geometry.

For example, the Hamiltonian and Lagrangian formulations provide elegant mathematical frameworks for understanding dynamics, translating the physical laws governing a system into mathematical structures that allow for analysis and prediction. Chaos theory, a subset of dynamics, explores systems that appear disordered or random but are governed by underlying patterns and deterministic laws.

In TGD, the phenomenal world, in other words, the observable and measurable universe, is perceived as a 4-dimensional shadow, that is, tangential projection of hyperspace H onto X^4. Symmetries in H are naturally static, but their isometric projection to the X^4 gives rise to the required dynamics for the complete theory.

This conceptualization adds a partly old, partly new perspective to our understanding of physical reality. One might envision H as a metaphysical realm akin to Plato's world of ideal forms, characterized by perfect global symmetries, which become realized in the world of projection. Symmetries in Plato's time were more like analogies and commensurable ratios. At the same time, the modern meaning of symmetry is rooted in formal group theory concepts like isometrics, transformations, and invariance.

However, Dr. Pitkänen had to invest significant time and effort to achieve proper dynamics in his model. This was when he served as a research worker at the Research Center of Neste Oy and as a teacher in the Department of Theoretical Physics, Helsinki, until 1992. "Things developed slowly," Dr. Pitkänen concedes, "But despite the occasional clouds of despair, I could sense that major changes were imminent, and I continued to push my theory forward."

About String Models

It is worth noting that unifying fundamental physics on this scale was still in its infancy when TGD was born. In the ensuing decades, this field became overwhelmingly influenced by string models. Alternative theories found it challenging to evolve under the colossal institutional program that spearheaded the first phase (1984-1994) and the second phase (1994-2003) of the superstring revolutions, the latter led by the "magic" M-theory of an American mathematical and theoretical physicist Edward Witten. Dr. Pitkänen frequently participated in Internet discussion boards criticizing the path taken by the mainstream, but what could a single man do against the institutional forces?

This led to an approximate 30-year era of dormancy, during which alternative theories beyond string models and loop quantum gravity were largely dismissed. Only in the 2010s did some of these alternate theories begin to gain recognition in public; particularly notable were Garrett Lisi's E8 theory[42], Stephen Wolfram's Fundamental Physics project[43], Eric Weinstein's Geometric Unity proposal[44], and the recent Postquantum Theory of Classical Gravity by Jonathan Oppenheim[45].

Nowadays, string models face growing criticism as a unification theory. Even though it succeeded in unifying gravity and QM by generalizing point-like particles to the string-like in spacetime manifold, the number of possible solutions and supergroup models grew up to imaginative scales, which we call landscape and swampland problems today. In a recent interview, Peter Woit posited that many touted achievements of string theorists are essentially reconfigurations of QFT[46]. The flexibility of string models allows for the incorporation of nearly any concept, yet this adaptability does not necessarily validate them as effective or useful theories.

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42 An Exceptionally Simple Theory of Everything (wikipedia.org)
43 The Wolfram Physics Project (wolframphysics.org)
44 Geometric Unity (geometricunity.org)
45 Jonathan Oppenheim, A postquantum theory of classical gravity?, 27 November 2023 (arxiv.org)
46 Theories of Everything with Curt Jaimungal Peter Woit: Unification, Spinors, Twistors, String Theory, 22 November 2023 (youtube.com)

The general view is that although string models have yielded beneficial mathematical innovations and present a workable quantum gravity model, they have yet to produce empirical evidence or find more relevant applications in theoretical physics. On the other hand, science communicators such as Brian Greene[47] and Michio Kaku, well-known advocates of string models, have significantly contributed to the advancement of scientific literacy. They have successfully introduced complex concepts, previously the domain of a chosen few, into public discussion.

TGD as Generalization of String Model

Among the numerous theoretical frameworks that propose to explain the mechanics of our universe—ranging from string models to loop quantum gravity, causal dynamical triangulation, and beyond—Topological Geometrodynamics stands out for its unique approach.

"The beauty of TGD lies in its simplicity and elegance," emphases Dr. Pitkänen. Unlike many other theories, TGD insists on the inherent four-dimensionality of our physical reality. In TGD, however, one gives up the assumption that one dimension is always time-like, as in the traditional Minkowski spacetime. "Spacetime regions with four spatial dimensions are also possible, and with wormhole contacts, they would be associated as building bricks of elementary particles."

Dr. Pitkänen discusses the fundamental concept of dimensions in TGD, starting with a historical perspective. "In the 1920s, a precursor to string models, the Kaluza-Klein theory, which originally excited Einstein, introduced the idea of a fifth dimension. However, in TGD, we ground ourselves in the four dimensions because that seems to align with our detector experiments and sensory experiences: bodies, fields, and waves in motion."

Kaluza-Klein's theory was an early attempt at a unified field theory that proposes extra dimensions beyond the familiar three spatial dimensions plus one time dimension we perceive in our universe. The theory suggests that the equations of electromagnetism can be derived from the gravitational field equations in five

[47] In the World Science Festival event, Brian Greene spoke with Edward Witten, David Gross, and Andrew Strominger, the prominent string theorists about Unifying Nature's Laws: The State of String Theory, 5 January 2024 (youtube.com). Contrary to Woit's opinion, Gross states in that discussion that QFT bears on many properties of String Theory, 49:49. Woit says it is the other way around.

dimensions by making one dimension compact and very small, which effectively ‘hides’ it from our everyday experience.

Addressing the long-standing divergence problems and the conundrum of quantum gravity, Dr. Pitkänen states, "TGD approaches these issues differently. Where string models define particles as strings instead of point entities assumed in GR and QFT, TGD conceives particles as surfaces rather than strings." He then continues into the nature of these bodies at the smallest conceivable scale, "Along the way of many interesting consequences, we can think of these trajectories of surfaces as ‘Bohr orbits,’ which takes us to the quantum mechanical side of TGD."

There are spacetime surfaces with 2-D M^4 projection, which look like string world sheets. They are impossible in GR but play a crucial role in the TGD explanation of dark energy and dark matter and in the model for forming astrophysical objects. The deformations of string-like objects appear in all scales, particularly in quantum biology[48] and cosmic scales. Holography, allowing us to realize 4-D general coordinates, implies that the mathematically poorly defined path integral, causing the divergence difficulties of QFT, disappears completely. Also, field quantization is irrelevant in TGD.

Dr. Pitkänen underscores the intuitive appeal of TGD's approach, "Surfaces are very much akin to what we observe in reality, precisely as TGD's mathematical model suggests. 4-D surfaces or their M^4 projections have boundaries. We directly see these boundaries and interpret them as boundaries of physical objects. The theory's concepts are intuitively appealing; you could continue reasoning about the world at any level. One could then reflect on whether these intuitive understandings have a mathematical counterpart within TGD." This dynamic between intuitive reasoning and formal mathematical modeling makes TGD intriguing and powerful.

The perspective of TGD allows us to bypass complex problems often encountered in string models, such as the landscape and swampland issues mentioned earlier. "In TGD, there's no necessity for larger supergroups or for compactifying, curling, or hiding extra dimensions," Dr. Pitkänen explains. "The world we perceive and measure, whether on a microscopic or macroscopic scale, consists of spacetime 4-surfaces.

[48] Johnjoe McFadden and Jim Al-Khalili are a few prominent scientists who have published a popular book about quantum biology “Life on the Edge: The Coming of Age of Quantum Biology” (2016). Also, see Robinson Erhard’s interview with Al-Khalili Jim Al-Khalili: The Fundamentals of Quantum Biology | Robinson's Podcast #185, 4 January 2024 (youtube.com)

These surfaces gain their dynamics from the action with variation principles and identities, which guide the changes in their properties based on H symmetries and topologies."

Different topologies are categories and modes of particles, their properties, and their interactions. This justifies and speaks for the first part of the selected name, Topological Geometrodynamics. The latter part refers to the geometrical representation of fields and dynamics.

Features such as higher-dimensional hyperspace, symplectic symmetries, and Kähler geometries, among others, may also seem synonymous with string models. However, despite frequent misconceptions, other elements distinguish TGD from prevailing string frameworks. Yet here, we talk about complexities that go beyond the purview of this article to delineate.

Pitkänen's approach is dedicated to casting classical and quantum physics in geometric terms. With an enthusiastic sparkle in his eyes, he asserts, "Einstein himself would have appreciated this. Although he would have had to concede that pseudotensors in GR were not quite up to the mark and that the quantum world is just as palpable as the classical one."

Discussing the mathematical foundations of TGD, Dr. Pitkänen acknowledges the inherent challenge of distilling such concepts into simpler terms. "Demystifying TGD requires navigating a multitude of mathematical disciplines, including topology, complex and differential geometry, and functional analysis," he says.

You cannot do away with the underlying complexity because it is the language we use to articulate the theory formally. After all, we are working with mathematical frameworks that are the fruits of some of the most brilliant minds in history, like Newton, Riemann, Clifford, Poincare, Lorentz, Minkowski, Einstein, Noether, Schrodinger, Dirac, Wheeler, to name a few. You must 'know' Einstein's relativity theories, classical mechanics, QM, and the Standard Model of particle physics. That is the physical arena where the physical unification is done. Also, the earlier unification theories are good to know because comparison is essential to understanding any theory[49].

Dr. Pitkänen continues, "If you are inclined toward quantum mechanics, you should be readily amazed by TGD's simplicity. For example, quantum TGD eliminates

[49] See Appendix 6 for a definition and description of the Theory of Everything.

the need for the first quantization, path integral formulation, and the ambiguous renormalization process commonly encountered in QFT."

However, one must acknowledge the eliminated parts to fully appreciate this simplification. In other words, simplicity is complicated.

TGD Comparison Tables

General Relativity (GR) vs. TGD vs. String Theory

Category	**GR**	**TGD**	**String Theory**
Scope of geometrization	Classical gravitation	All interactions and quantum theory	Unification of all fundamental forces
SPACETIME			
Geometry	Abstract 4-geometry	Sub-manifold geometry	2-D string world sheets in 10-dimensional (or higher) target space
Topology	Trivial in long-length scales	Many-sheeted space-time	Calabi-Yau manifolds
Signature	Minkowskian	Also Euclidean	Primarily Minkowskian
FIELDS			
Classical	Primary dynamical variables	Induced from the geometry of H	Emergent from string vibrations
Quantum fields	Primary dynamical variables	Replaced with the modes of classical WCW spinor fields	Replaced with fundamental superstrings and branes
Particles	Point-like	3-surfaces	1-dimensional strings
SYMMETRY			
Poincare symmetry	Lost	Exact	Partially preserved
General coordinate invariance (GCI)	True	True - leads to holography and ZEO	Preserved
Supersymmetry	Supergravity	Super-symplectic invariance	Fundamental symmetry

DYNAMICS			
Equivalence Principle	True	Remnant of Poincare symmetry at QFT limit. Realized at the level of vertices in quantum theory	Preserved
Newton's laws	Lost	8-D generalization realized at vertices. Second fundamental form <--> acceleration <--> 8-D analog of Higgs field	Emergent in low-energy limits
Einstein's equations	From GCI and EP	Quantum analog at graviton vertex Remnant of Poincare invariance at QFT limit	Derived from string dynamics
Bosonic action	Einstein-Yang-Mills action	Kähler action + instanton term + volume term	Derived from string worldsheet action
Cosmological constant	Suggested by dark energy	p-Adic length scale dependent coefficient of volume term	Varies with compactification
Fermionic action	Dirac action	Modified Dirac action for induced free second quantized spinor fields in H	Emergent from supersymmetric partners
Newton's constant	Given	Predicted in terms of CP_2 size scale	Emergent
Quantization	Fails	Only for free spinor fields in H. Quantum states as modes of formally classical WCW spinor field	String quantization rules

Standard Model (SM) vs. TGD vs. String Theory

Category	SM	TGD	String Theory
SYMMETRY			
Origin	From empiria	Reduction to $M^4 \times CP_2$ geometry	From spontaneous compactification and/or branes
Color symmetry	Gauge symmetry	CP_2 isometries	Gauge symmetry from spontaneous compactification/D-branes
Color	Analogous to spin	Analogous to angular momentum	Analogous to spin
Elektroweak symmetry	Gauge symmetry	CP_2 holonomies	Gauge symmetry related to spontaneous compactification/D-branes
Symmetry breaking	Higgs mechanism	CP_2 geometry and p-adic thermodynamics	Various mechanisms
SPEKTRUM			
Elementary particles	Fundamental	Consist of fundamental fermions	Excitations of superstrings
Bosons	Gauge bosons, Higgs	Gauge bosons, Higgs, pseudo-scalar as fermion-antifermion bound states	Gauge bosons from open strings
Fundamental fermions	Quarks and leptons	Quarks and leptons or only quarks (leptons as local 3-quark composites)	Quarks and leptons from string states
DYNAMICS			
Primary degrees of freedom	Gauge fields, Higgs, and fermions	3-D surface geometry and free H-spinors	Vibrational modes of superstrings
Classical fields	Gauge fields, Higgs	Induced metric, induced spinor connection, $SU(3)$ Killing vectors of CP_2	Emergent from low-energy limits
Quantal degrees of freedom	Gauge bosons, Higgs	Induced second quantized free spinor fields of H	Quantized string excitations

Massivation	Higgs mechanism	p-Adic thermodynamics with 4-D generalization of superconformal symmetry and supersymplectic invariance	Compactification and string tension
QUANTUM DYNAMICS			
Quantization	Fails	"Do not quantize" at the level of WCW. Second quantization of free spinor fields at the level of H.	Quantized string actions

Investigating Anomalies

One characteristic way of developing TGD has been to pinpoint current open problems in many related areas of science. Anomalies serve as a grounding element for planning future experimental tests for the TGD theory.

Dr. Pitkänen emphasizes the theory's capacity to reconcile these with a more comprehensive understanding of the physical world. He states, "TGD's framework offers a compelling perspective on various anomalies that traditional models struggle to explain. Consider, for instance, the phenomenon of dark matter. Here, TGD's interpretation involving macroscopic quantum coherence and large effective Planck constants provide a fresh lens through which we can view these anomalies, not as isolated quirks, but as integral parts of a broader physical narrative that Topological Geometrodynamics offer. Moreover, the theory's approach to the reversal of time's arrow in macroscopic quantum jumps is particularly interesting," Dr. Pitkänen continues. "It suggests a deep-seated interplay between physics and consciousness, as evidenced in phenomena like the phase-conjugate waves in lasers and the precognitive aspects of neural activities observed in neuroscience."

"Lastly," he adds, "TGD addresses the anomalies related to spacetime and field concepts by introducing many-sheeted spacetime and monopole flux tubes. This helps us understand complex astrophysical and cosmological phenomena and sheds light on unresolved particle physics and hydrodynamics issues."

The following is a list of the most important anomalies that have influenced maturing TGD.

Dark Matter

Many of these anomalies can be elucidated through the TGD perspective on dark matter, contributing to its conceptual evolution into a number-theoretic vision. This encompasses a broad range of phenomena:

- **Quantum Coherence at Macroscopic Scales:** TGD's interpretation involves a large effective Planck constant (h_{eff} and $h_{gr} = h_{eff}$), facilitating quantum coherence over extensive scales. Here, the scales vary from molecular to cosmological scales. The magnetic body of the system is always involved since the time reversal of the magnetic body induces effective time reversal in long timescales at the level of ordinary matter. For instance, DNA, cell organisms, gravitational magnetic bodies of Earth, and the Sun play a key role in the TGD-based quantum gravitational view of quantum biology, the electric body of Earth, etc.
- **Neuroscience and Biology**: Anomalies such as the influence of Extremely Low Frequency (ELF) radiation on mammalian brains, the Pollack effect, and the mechanisms underlying biocatalysis challenge existing scientific understanding. For instance, the Pollack effect, manifesting a reversal of the arrow of time, aligns with the phenomenon where a portion of protons transitions to magnetic flux tubes, forming a dark phase.
- **Physics**: The mysterious disappearance of valence electrons in rare earth metals upon heating and the potential reality of phenomena like ‘Monoatomic Gold’ underscore the role of dark matter in these processes.

Reversal of Time's Arrow in Macroscopic Quantum Jumps

Anomalies pointing towards the reversal of time's arrow in macroscopic quantum jumps have been instrumental in shaping the zero-energy ontology within TGD:

- **Laser Physics**: The existence of phase-conjugate waves adhering to thermodynamics in reverse temporal direction is a non-controversial effect, paralleled in acoustics.
- **Neuroscience**: Observations like those by Libet[50], indicating that neural activity precedes actions such as raising a finger. This suggests a reversal in energy dissipation, challenging the standard interpretation of the second law of thermodynamics.
- **Biology**: Homeostasis, particularly the ability to maintain non-stable (critical) points, demands complex multi-level control systems. In TGD, this is understood as a process where the arrow of time on a magnetic body continuously reverses.

Anomalies in Spacetime and Field Concepts

The third category of anomalies relates to the generalization of spacetime and field concepts in TGD, particularly many-sheeted spacetime and monopole flux tubes:

- **Astrophysics and Cosmology**: Anomalous correlations at cosmological scales, including cosmic filaments and dark matter in galaxies, are attributed to monopole flux tubes.
- **Particle Physics**: Besides color confinement, issues like the proton spin problem and the strong CP problem in QCD indicate gaps in current theoretical models, posing monopole flux tubes as a fundamental underlying mechanism.
- **Hydrodynamics**: TGD proposes novel interpretations for phenomena like turbulence and the many anomalies in water thermodynamics, suggesting the involvement of classical Z^0 force, vortex-related monopole flux tubes, and dark matter.

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[50] Various authors, Libet's experiment: A complex replication, 11 July 2018 (sciencedirect.com)

- **Condensed Matter Physics**: High-temperature superconductors and the discovery of exotic phases are among the anomalies that challenge existing frameworks, potentially finding explanations within the TGD paradigm.

TGD's ability to take these disparate anomalies and weave them into a coherent theoretical tapestry makes it particularly powerful. This harmonization of intuition and formalism sets TGD apart, offering a promising concrete way for exploring the depths of physical reality.

WCW & ZEO

In the late 1980s, Dr. Pitkänen grappled with a significant turning point. A personal crisis, marked by a divorce, a mental breakdown, and a spiritual awakening in the late 1980s, played a pivotal role in shaping his intellectual journey. Deep thinkers often experience mental strain from wrestling with complex theories. "Add societal expectations into the mix, which can become a real challenge," he reflects. The crucible of these internal and external pressures, he believes, catalyzed what he identifies as breakthroughs in his theoretical formulation: the World of Classical Worlds (WCW) and Zero Energy Ontology (ZEO).

"But where do these generalized particles, represented as spacetime surfaces X^4, exist?" he asks rhetorically. "Well, individually, spacetime surfaces are the 'classical worlds.' Together, they form the World of Classical Worlds. One of the classical constraints imposed by the hyperspace H's Minkowski component is the causality boundary due to the finite value of the maximal signal velocity." This speed limits light and gravity from interacting at a maximum rate—known as the speed of light. These particles trace diamond-shaped world lines, a concept already familiar from spacetime diagrams in relativity. Dr. Pitkänen often refers to this by the Causal Diamond (CD) concept.

In TGD, the phrase ‘quantization without quantization’ refers to the unique approach to quantization where classical fields, such as gauge fields and metric, are not primary field variables and thus are not quantized in the conventional sense. Instead, classical induced fields appear in vertices, with only fermionic 2-vertices in these fields, avoiding the usual divergences associated with 3-vertices. Gauge bosons, Higgs, gravitons, etc., are treated as fermions and anti-fermions bound states. The theory remains classical at the WCW level, with fermions quantized as free fields in H but described classically in terms of anti-commuting gamma matrices and spinor structures in WCW. The quantum jump is the only genuine quantum mechanical aspect, defining what is meant by 'quantization without quantization' in TGD.

Dr. Pitkänen elaborates on the spinor structure, "It is a mathematical entity linked with quantum mechanics, akin to a fingerprint for elementary particles with half-integer spin, like electrons and quarks. It also has a purely geometric meaning. TGD assigns a spinor structure to each 4-surface induced by imbedding hyperspace $H = M^4 \times CP_2$. Integrating quantum mechanics into the WCW's geometry is one of TGD's other critical innovations, marking a departure from conventional quantum mechanics. Quantum fields in WCW reduce to purely classical spinor fields, 'quantization without quantization,' the Wheelerian principle mentioned earlier. There is, however, a second quantization of free spinor fields in $M^4 \times CP_2$ free of divergence problems."

What is Zero Energy Ontology, then? Dr. Pitkänen explains, "ZEO plays a critical role in the World of Classical Worlds. Both are new concepts introduced in the context of TGD. ZEO fundamentally alters the standard quantum mechanical view of what constitutes a physical state."

"In traditional quantum physics, a state is associated with a definite positive energy," he continues, "In contrast, ZEO introduces the concept of zero-energy states. Each zero-energy state is a pair of positive and negative energy states located at the opposite boundaries of a causal diamond. When considering the past and future states, the total energy is zero, hence the name Zero Energy Ontology."

ZEO is often confused with zero-point energy, but they are different concepts. Another confusion is that physical states have zero energy, as in some theoretical proposals. This is not the case either. The zero-energy property only implies that energy and other quantum numbers are conserved.

Next, let us dive deeper into this concept of the Causal Diamond. In TGD, a CD is the region of Minkowski spacetime between two null lines or light cones, which could be considered an intersection of the future and past-directed light cones.

In this topic, Dr. Pitkänen gives a longer lecture that one could regard as a culmination of contemplating deeply these three concepts:

"In this framework, the symmetries of the light-like 3-surfaces, denoted by Kac-Moody symmetries, permit deformations of the partonic 2-surface in the light-like 3-surface interior, underlining the effective 2-dimensionality of the metric. This framework allows the specification of 'preferred extremals' induced by a global selection of $M^2 \subset M^4$ as a plane belonging to the tangent space of X^4 at all points. These preferred extremals enable the assignment of well-defined quantum numbers to realize ZEO.

The center of mass degrees of freedom within a CD are not mere gauge-like degrees of freedom. Sub-CDs can have non-trivial correlation functions, and the largest CD defines the infrared cutoff. In the WCW setting, ZEO addresses various challenges in quantum gravity and quantum cosmology, such as the problem of time in quantum gravity and the cosmological constant apparent in Einstein's field equations.

ZEO also leads to a novel interpretation of a quantum jump and the arrow of time. Here, the concept of zero energy is critical. The total quantum numbers of the Universe are zero because the Universe is a quantum superposition of classical time evolutions between initial and final states, represented by the past and future boundaries of the CD. Quantum state evolution in ZEO is a process of quantum jumps that replaces a CD with a new one, updating or 'reincarnating' the state of the Universe.

Notably, the arrow of time is not fixed in ZEO. Each quantum jump can either preserve or flip the arrow of time, a phenomenon tightly related to consciousness phenomena in TGD. This is where the distinction between the lowercase 'cd' and the uppercase 'CD' comes into play. Lowercase 'cd' is a union of two half-cones of M^4 glued together, whereas uppercase 'CD' is the Cartesian product of 'cd' and CP_2.

Furthermore, the ZEO approach implies the strongest form of holography due to general coordinate invariance. Time evolutions are equated to pairs of ordinary 3-D states identified as initial and final states of time evolution, yielding an analog of soap film dynamics. In this sense, 3-surfaces at the passive boundary of the CD correspond to 4-D minimal surfaces, much like soap films spanned by a frame with fixed and dynamically generated parts.

Finally, this unique structure enables the Zeno effect to be observed, where systems tend to remain in their initial state when continually measured. This is a distinctive feature of sequences of small state function reductions in TGD. Furthermore, quantum jumps in ZEO replace a state with a new one without violating classical determinism, resolving the paradox of merging deterministic classical physics with probabilistic quantum physics. In other words, it resolves the quantum measurement problem[51]."

Shortly, WCW represents all possible universe states. Each state is depicted as a pair of 3-surfaces in the ZEO at the Causal Diamonds' past and future boundaries. CDs are spacetime regions encapsulating all potential events between two points in time. Each CD corresponds to a distinct universe state in the WCW. ZEO introduces zero-energy states, consisting of positive and negative energy states at opposite boundaries of a CD. It frames quantum evolution as transitions between CDs, marking the idea of quantum jumps in TGD.

This is the whole idea in the geometric core of TGD, told in mathematical concepts, theoretical postulates, and physical interpretations. As astonishing as this might sound, these concepts also affect our understanding of the nature of consciousness within the TGD framework.

Adelic Physics as Description of Cognition

Speaking with Dr. Pitkänen evokes a sense of attending Apple's annual Worldwide Developers Conference. When you think you have reached the end, there is always 'one more thing.' Not only does the geometrization program in TGD encompass classical particle fields, but it also extends to QM. This is when terms like p-adic numbers, Adelic physics, and $M^8 - H$-duality come into play—three of those 'one more thing.'

In mathematics, p-adic numbers are an extension of the set of rational numbers. The 'p' stands for prime, as the prime numbers parameterize these number systems. Unlike the real number system, where the 'closeness' of two numbers is determined by the absolute difference, in the p-adic number system, two numbers are 'close' if their difference is divisible by a high power of p. p-Adic numbers find applications in various

[51] Stephen Adler, Why Decoherence has not Solved the Measurement Problem: A Response to P.W. Anderson, p.9, March 2002 (arxiv.org) discusses how decoherence does not solve the real quantum measurement problem that relates to how to understand the transition from a quantum superposition to a definite observed outcome, how to justify the use of Born rule. One route is the Many-World theory, other is some non-local hidden variable theory such as Bohmian pilot wave theory. Copenhagen quantum receipt proposes that magic just happens; forget philosophy and calculate. See also Johan Hansson, The Quantum Measurement Problem, 31 March 2021, International Journal of Quantum Foundations (ijqf.org).

areas of mathematics, like number theory and theoretical physics, because they capture mathematical phenomena not visible in the realm of real numbers.

The term Adelic physics arises from the mathematical concept of adeles. Adeles are a system that unifies various completions of a number field (a finite extension of the field of rational numbers). In Adelic physics, physical theories are constructed by incorporating the adeles as a framework, often to oversee the challenges posed by p-adic numbers. This unifying framework allows for the simultaneous treatment of real and p-adic numbers, offering new ways to describe and investigate physical phenomena.

"The Adelic physics in the number theoretical framework M^8 in TGD opens the door to a fruitful analogy between the fundamental processes of physics and consciousness," Dr. Pitkänen reveals, daring to unlock the closet. "This brings us closer to a unified understanding of mind and matter in a single formal framework."

There is an intriguing story along his history in the middle of the 1980s that Dr. Pitkänen shares with me:

“The experience was as if I had connected with something I called the ’Big Mind.’ Gradually, it started feeling like I had fused with this ’Big Mind’ in that state of consciousness: the interpretation of Brahman equals Atman seemed natural, as I realized much later. It lasted a week or so.

I asked questions and received answers, initially as if they were written on a screen but then as direct internal speech. Amusingly enough, it brings to mind a ChatGPT session! The state lasted for over a week. I was flooded with ideas that I later developed and interpreted. Of course, psychiatrists would diagnose this as an ‘acute psychosis.' In Eastern cultures, it might have been referred to as enlightenment.

I was faced with a choice between Neste Oy and my work. I left Neste Oy after this grand experience in 1985. Soon after, I was invited to Schrödinger's 150th-anniversary symposium and Potsdam to Einstein's summer house. This opportunity paved the way for my teaching position at the university.”

Around 1990, Dr. Pitkänen found the works of Indian philosopher Jiddu Krishnamurti after his ‘Big Mind’-experience. The books documenting conversations between Krishnamurti and the American theoretical physicist David Bohm fascinated him particularly. "I came to know Krishnamurti after the experience in my quest to find out if anyone else had experienced something similar. Krishnamurti's experiences were strikingly similar to mine. He often referred to it as ‘the process.’ I became convinced that human experience, cognition, and consciousness could not be reduced to mere physical interactions; they are not subjects and objects to be experienced, but a dynamically changing state," reflects Dr. Pitkänen. Bohm carefully studied perception and invariance in the long appendix of his book "The Special Theory of Relativity" in 1964.

Dr. Pitkänen began to see the potential for an analogy of consciousness, awareness, and cognition within a quantum mechanical framework. This framework could formalize experiences and qualia, even if the quantum forms were not the qualia themselves. "This laid the groundwork for a theory of cognition and formed a number theory M^8 correspondence to the hyperspace H," Dr. Pitkänen concludes, adding yet another layer to his multifaceted theory. But that is an expedition of another time and scope.

Part III: Closing Words

Here, we have dealt only with the surface of TGD, its early history, and central concepts, concentrating on the original geometrization program. There is a sense of tranquility when we touch abstract concepts, which is punctuated by moments of revelation when I comprehend something that connects disparate pieces of the puzzle to the grand image and reality I am acquainted with.

Conversing with Dr. Pitkänen is a fluid journey that meanders from fond reminiscences, tribulations, and misfortunes to the details of his theory. Although the main principles have stood the test of time, a staggering volume of material has been produced over the decades, and there is no straightforward way to see the current state of the project.

The development path of the theory somewhat reminds me of Einstein when he joked with himself after publishing the 'final release of theory' in 1915, "Every year he revokes what he's written the year before."[52] Einstein improved the details until very late in his age. In the note of the fifth edition of the book "The Meaning of Relativity," published in 1954, Einstein, in his 1970s, writes, "For I have succeeded-in… in simplifying the derivations as well as field equations."

A more comprehensive review should include the development of the number theoretical dual and many other TGD aspects. But, to keep 50 years story relatively short, I have concentrated mainly on the beginning era of TGD, namely a) the global energy problem, which could also be called the Poincaré symmetry problem in GR that motivated the birth of TGD, b) the choice of hyperspace $H = M^4 \times CP_2$, which unifies gravity and the Standard Model in a single geometric framework with c) explanations of how symmetries become actualized in spacetime, field equations, and quantum mechanics by the induction process. I have left out most of the Quantum TGD, number theoretical TGD, and TGD-inspired theory of consciousness, which form 75% of the theoretical framework Dr. Pitkänen has developed over the years.

TGD theory has continuously evolved since the 1980s and the early 21st century. When examining earlier papers, it is not immediately apparent which theory elements remain relevant and which have been discarded or superseded. Consequently, Dr. Pitkänen advises consulting his more recent articles and books, but

[52] Albrecht Fölsing, (transl. Ewald Osers), Albert Einstein: A Biography, p.374 (1993)

the Big Picture might be hard to see even then. You are likely to enter an atelier full of artist's works in progress.

As the theory expands in breadth and depth, we continuously face the challenge of maintaining our mental focus and aligning our understanding with the correct concepts in our frequent group discussions and Zoom meetings. What the trivial and canonical parts of the TGD theory are, and which parts are novel or modifications of the known theories, were challenging to determine.

Another tricky thing in studying TGD is understanding the relations when certain parts of the theory are generalizations or analogies of the established models. There is much to do on that side of the formalization of TGD theory.

For seasoned experts, even though they might be interested in alternative Theory of Everything proposals, researchers often face time constraints when familiarizing themselves with unification theories. I have watched several online debates where participants openly admit that they have not examined their opponent's theory. What is the use of such discussion?

Over the years, I have come to the conclusion that researchers would need to arrange private discussions with the theory's developer(s) to gather the necessary in-depth understanding. I do not see any signs of that kind of activity in the current online discussions.

Learning the details of theories like TGD could take months or, more realistically, years. One would need solid motivation to arrange a time for it. Related to that, it is always easier for a student and professor to start with a widely known framework with a lot of study material from the community. As far as we know, TGD has not been taught in any school. This essay hopefully narrows down that knowledge gap.

Academic Rigidity

The academic environment could have been more welcoming to alternative proposals or modifications to GR at the birth of TGD. The reasons for the aloof attitude are complicated.

It is more common than not for students, let alone laypeople, to attempt to uncover flaws, gaps, and inconsistencies in Einstein's theories. There is an oddly compelling desire to challenge the theories put forth by arguably the most famous physicist in history. Throughout history, there have been many who have opposed relativity theories for various reasons. For instance, the first time Einstein got into the news in the United States, his theory was told to be understood only by twelve people in humankind[53]. This was a red flag in a society where everyone should have access to everything. Elitistic start turned slowly into admiration so that in 1946, Einstein was the most celebrated physicist in history on the cover page of Time magazine, and the Person of the Century on December 31, 1999.

How should you have dealt with the subject as a teacher or professor toward the end of the 20th century? The default expectation was for students to eventually accept relativity and quantum theories without much questioning or doubting their foundations publicly. Those who did not align well with the status quo were often stigmatized as science deniers, especially if they worked outside a reputable institution.

In physics, theories are far less complete than in mathematics, for example. Even hundreds of successful tests do not guarantee that there will not be anomalies that shake the grounds of the theory in the future or that we cannot find duals to the theory or other improvements or generalizations. No consensus or Nobel price can give 100% security on that matter. That could imply constant evaluation and review of the new proposals, but for some strange reason, theoretical physics in fundamental questions seems more vulnerable to dogmatism than any other discipline.

According to Dr. Pitkänen, theoretical physics is particularly known for its stagnating nature, rooted in its physicalist reductionism, and its exceptional success in dealing with the subject matter, especially after the nuclear forces were harnessed. The scientific community is understandably opinionated as it grapples with the most

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[53] Albrecht Fölsing, (transl. Ewald Osers), Albert Einstein: A Biography, p.447 (1993)

profound aspects of reality, built upon centuries of empirical research, experiments, and established theories. Any novel idea must undergo rigorous verification within a scientific crucible to be considered other than premature woolgathering.

This tension between career progression and pursuing scientific breakthroughs is a common dilemma since one cannot become renowned only by agreeing with already-known theories. However, only a tiny fraction of new ideas survive. Groundbreaking ideas necessitate compelling evidence and arguments peer-reviewed by professionals and the broader scientific community.

Over the decades, more trustworthy and precise theories will emerge and become part of the toolbox used to decipher the laws and structures of the universe. This requires putting egos aside and working for the public good rather than personal credit.

Unfortunately, good ideas can also get submerged in the deluge of information accompanied by sociological issues. Noether's work was one of those. But, when time was ripe, Noether's theorems were vindicated.

Is It Realistic to Stipulate World Equation?

One question often asked is about a simple and beautiful world equation that could present the whole theory.

In June 2023, I visited CERN in Geneva and found a t-shirt with an equation representing the Lagrangian of the Standard Model of particle physics[54]:

$$\begin{aligned}\mathcal{L} = \quad & -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\ & + i\bar{\psi}\not{D}\psi \\ & + \psi_i y_{ij}\psi_j\Phi + \mathrm{h.c.} \\ & + |D_\mu\Phi|^2 - V(\Phi)\end{aligned}$$

While this equation is fundamental to understanding quantum fields and forces, it does not encompass gravity, dark matter, dark energy, or matter-antimatter asymmetry. It thus is not a complete 'world equation.' Moreover, including gravity in this framework leads to non-renormalizable divergences, highlighting the need for a more unified theory.

Dr. Pitkänen has yet to provide a single, unified equation for his theory. This is partly because his framework incorporates numerous intricate and abstract concepts. Seemingly, he has a coherent picture in his mind, but can it be written down so that the same coherence gets transferred? Ideologically, it is uncertain whether quantum measurement, conscious experience, or cognition can be modeled deterministically. Nevertheless, TGD presents a fascinating framework for quantum state computation with a time arrow that alternates.

TGD's reach extends beyond particles and interactions. The theory spans from the smallest particles to the largest cosmic structures and even into biology. Thanks to the holography principle, TGD predicts repeating the same fundamental structures across all scales in the universe. This principle allows for a vast number of applications and empirical predictions.

The vacuum function, defined by the classical bosonic action, could be a starting point for the world equation. Dr. Pitkänen refers in his blog post about the master

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[54] Julia Woithe, Gerfried Wiener, and Frederik Van der Veken, Let's have a coffee with the Standard Model of particle physics!, 30 March 2017 (iop.org)

formula[55] to the concept of supersymmetrization of the WCW Kähler function by adding a modified Dirac action. He emphasizes that the bosonic action from the requirement of supersymmetry determines the modified Dirac action. Furthermore, Dr. Pitkänen suggests that bosonic field equations for the spacetime surface follow hermiticity conditions. The modified Dirac equations are claimed to ensure the conservation of the fermion number.

Regarding the challenge of creating fermion pairs, the blog post proposes a topological description for reaction vertices and discusses the potential role of exotic 4-D smooth structures in the formulation. The master formula will likely be an interconnected set of principles and equations rather than a single, simple equation. TGD can, however, provide a route to non-trivial scattering amplitudes from second quantized spinor fields restricted to 3-surfaces, according to Dr. Pitkänen. This implies the possibility of a simplified articulation of the master formula, a challenge left for future investigations.

There are many other questions, too. For instance, how are hyperspace symmetries apparent in the action, and how can we be sure that the maximal symmetry does not exclude realistic spacetime geometries? Also, with generalizations and symmetry requirements, is there any danger of getting astray with fine mathematics, which has no meaning in the physical sense?[56]

While sophisticated mathematical frameworks can provide deep insights, they must be tethered to physical reality through experimental verification or observational evidence if a scientific physics theory is the primary goal. Ultimately, theories must be judged by their ability to describe and predict known physical phenomena accurately. However, it is much easier to state that idealized scientific method than to implement it. Sometimes, it takes decades to reach a point in a theory when practical, relevant experiments can be done. And it would require at least a team, sometimes hundreds or thousands of people, to work with as in high-energy particle physics or cosmology missions.

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55 Matti Pitkänen, Exotic smooth structures at space-time surfaces and master formula for scattering amplitudes in TGD, 25 June 2023 (tgdtheory.fi)

56 For critically written books about the topic, see for example: “Not Even Wrong” by Peter Woit (2006), “Lost in Math” by Sabine Hossenfelder (2018), and “Make Physics Great Again” by Alexander Unzicker (2023)

Further Information about TGD

As TGD has evolved, Dr. Pitkänen has taken on the Herculean task of summarizing the development of TGD on several occasions in history with updated current state papers. Yet, the scope of one man's effort has its limits. With his dedication to addressing contemporary problems and anomalies in physics and science through TGD, Dr. Pitkänen has produced a meandering volume of written material, which is sometimes hard to categorize. This striking-the-current-open-problems methodology has kept Dr. Pitkänen busy, and his theory has been under constant theoretical evaluation and development process in the last two decades.

The resulting reports[57] contain around 1,200 blog posts and close to seven hundred articles, many of which intersect with the content of his blog posts. Articles are often updated, so you cannot easily pinpoint their first publication date, but blog posts have a definite timestamp. TGD manuscripts have been compiled into dozens of eBooks, accessible on his websites, the ResearchGate platform, the ArXiv preprint server, and various scientific journals, including Springer[58], the Prespacetime Journal[59], and Metodologia[60].

Highlighting Dr. Pitkänen's monumental contribution to the field, one standout publication is his 920-page work, "Topological Geometrodynamics: Revised Edition," by Bentham Science Publishers in 2016. This volume distills the essence of TGD, a testament to his years of research and analysis.

Nevertheless, the past seven years have brought refinements and changes to the details of TGD[61]. To enrich understanding, the recent lectures[62] [63] [64], video interviews[65]

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[57] In 2023, I scraped all TGD blog posts and used machine learning algorithms to categorize material and summarize them with OpenAI API. Material is published in GitLab project: Topological Geometrodynamics / TGD Manuscript (gitlab.com)

[58] Philosophy of Adelic Physics, New Trends and Advanced Methods in Interdisciplinary Mathematical Sciences, Springer, Sham (2017)

[59] The Miracle of Existence according to Theoretical Physicist Matti Pitkänen: 30 years of independent research, Prespacetime Journal, Vol 1, No 4 (2010)

[60] Matti Pitkänen, Summary of Topological Geometrodynamics, Metodologia, Issue I, 2020

[61] Matti Pitkänen, The Latest Progress in TGD, 29 December 2023 (tgdtheory.fi)

[62] Matti Pitkänen, Gravitational quantum coherence and living matter - TGD view, 24 May 2023, Taormina TSC Conference (youtube.com)

[63] Matti Pitkänen, Topologinen geometrodynamiikka, 22 April 2023, Luonnonfilosofian seura (youtube.com)

[64] Mesokosmos, TGD-teoria: Kvanttifysiikan geometrisointi ja tietoisuuden teoria, 18 April 2023 (youtube.com)

[65] Kvanttifyysikko Matti Pitkänen ja taiteilija Sini Kunnas juttelevat Masaru Emoton työstä, 17 May 2018 and "Tajunta ja tietoisuus". Kvanttifyysikko Matti Pitkänen & kuvataiteilija Sini Kunnas, 19 September 2018 (youtube.com)

[66], and podcast appearances[67] [68] featuring Dr. Pitkänen offers additional insight into the current state of TGD. Most of the material and links can be reached from tgdtheory.fi and curriculum page[69]. These resources provide valuable perspectives and updates on the theory. For the latest developments and the most accurate state of TGD, one should consult Dr. Pitkänen directly. To answer your questions, you could also try the TGD Explorer[70], a custom GPT module in the OpenAI ChatGPT web application.

[66] RTV, Juhan juttusilla Matti Pitkänen – osa 1, 10 September 2019, and Juhan juttusilla Matti Pitkänen - osa 2, kvanttibiologia, 23 November 2019 (youtube.com)
[67] Mesokosmos, Kvanttikietoutumia ja koherenttia maailmankuvaa etsimässä, osa 3/3, 17 March 2020 (mesokosmos.com)
[68] Mesokosmos, Opus 1: Ajankääntöjä ja kausaalitimantteja, 20 May 2020 (youtube.com)
[69] Matti Pitkänen, Curriculum Vitae and Collected Research Papers (tgdtheory.fi)
[70] TGD-Explorer (chat.openai.com)

About Research Methods and Writing Process

This essay is based on a close collaboration with Dr. Pitkänen that started in September 2019 and includes over 1,000 emails and a hundred hours of live dialogue. I have not referred much to specific places in his papers, as Dr. Pitkänen has validated his quotes in this essay, and they represent the latest and fresh expressions of the details of the theory.

When we started, my background lacked studies in theoretical physics. I had to spend considerable time catching up with modern knowledge in the area that deals with the subject and finding out what part of TGD is standard physics and what is new. It has been a wavering time since there are no courses or study programs to start with TGD. The main study method has been a slow, organic way of listening, asking, and creating text summaries, structured documents, and presentations.

My motivation is driven by the unification theme in science and philosophy, which I believe gains the necessary depth through studying alternative theories like TGD. Learning and reflecting on the current mainstream consensus with alternative dissident theories is a fruitful ground for developing critical thinking. One important thing I have learned about studying the theory in this discussion is that one needs to build trust and ground for a long-term conversation and try to absorb as much as possible. If you start with a cold, objective debate and criticism, you are likely to never get into the deep meanings and correct interpretation of the theory. That does not mean that one should not think critically about every aspect of the theory, but it should come only after the details are correctly understood and meant by the founder of the theory.

In a way, the essay documents studying the theory, organizes content to a temporal and conceptual whole, and tries to make the result accessible to a broader audience. I share a similar goal with Professor Sean Carroll in his recent book series, "The Biggest Ideas in the Universe." Some people, not intending to be theoretical physicists working on complex equations and calculations in schools and laboratories, still wish to understand the meaning behind these equations and concepts. This approach goes beyond popular science books, which often lack the depth to relate personal insights to rigorous theories.

Tuning thoughts to a suitable mindscape is essential to achieve this goal. The easy-to-approach historical introduction, given in the first part of the essay, should orient readers' minds properly, like preparing instruments for a concert or tuning a sitar for an evening raga. It connects the enduring endeavor to understand the world and acknowledges that many modern, widely accepted theories and concepts have centuries-long traditions. History teaches us about the development of ideas, helping us build on past works rather than reinventing the wheel. A right mindset requires scientific virtues such as curiosity, discrimination, humbleness, endurance, and honesty; the very same virtues shared by any truth-seeker.

In theoretical physics, especially the area that investigates fundamental laws, I see the natural sciences as one of the purest forms of asking about the constituents of life. Many scientists have initiated to philosophy to enhance their toolbelt for solving challenging conceptual issues in physics, like Tim Maudlin[71], David Albert[72], Lee Smolin[73], Carlo Rovelli[74], and Sean Carroll[75], to name a few. Philosophy is used to study arguments on which theories and interpretations of empirical results are founded[76].

I have sought the best ways to express these ideas, establishing a coherent link between highly abstract concepts and the theory's mathematical foundations while making them as concrete and relatable to real life and basic intuition as possible. Occasionally links to Wikipedia, Britannica, and Stanford online encyclopedias are provided for quick links to read further information.

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71 Professor Tim Maudling founded a John Bell Institute for the Foundations of Physics (johnbellinstitute.org) at Hvar, Croatia to address the special need for sorting out fundamental questions in physics, mathematics, and philosophy. Finland also has an independent Physics Foundations Society (physicsfoundations.org) to address foundational questions.

72 Professor David Albert is a Philosophical Foundations of Physics M.A. Program director at Columbia University, New York.

73 Lee Smolin is an American theoretical physicist, a faculty member at the Perimeter Institute for Theoretical Physics, an adjunct professor of physics at the University of Waterloo, and a member of the graduate faculty of the philosophy department at the University of Toronto. In his essay Why philosophy?, June 2014 (leesmolin.com), he writes: "I read the great natural philosophers of the past because I understand myself and my fellow physicists to be trying to answer the questions that drove them and because, in spite of the limitations under which they worked, wrestling with the confusions of much earlier versions of physics, without the benefit of centuries of progress, they sometimes understood the problems we face more deeply than many of my colleagues today."

74 Carlo Rovelli is a professor of physics at the University of the Mediterranean in Marseille, France, who works on quantum gravity and on foundations of spacetime physics.

75 Sean Carroll moved to the John Hopkins Department of Philosophy on July 1, 2022. See his interview about science and philosophy, which shows his interest in the philosophy of science from early on: Science and Philosophy: An Interview with Sean Carroll | Fabio Gironi, 2011 (academia.edu) and the conversation between him and Brian Greene: Quantum to the Cosmos: A Bried Tour of Everything, 16 September 2023, 41:02 (youtube.com).

76 Carlo Rovelli, Physics Needs Philosophy. Philosophy Needs Physics, 3 May 2018 (springer.com)

This essay carefully explains and articulates the key concepts of TGD's geometrization aspect. For topics related to the number theoretical, cognitive, or quantum aspects of TGD, those areas could be the subject of future essays or research projects.

In the structure of the essay, I have used a well-known pedagogical approach to tell first what I am going to tell, then tell the thing, and finally tell what I just told. References, a timeline, concept maps, and vocabulary are included at the end of the essay to aid readers, especially those new to fundamental physics. I firmly believe that spending time with these materials can educate readers about the central questions in unification theories.

My qualitative approach resembles a hermeneutic method known in literary and other humanistic studies, where the researcher immerses themselves in the subject, internalizing and cultivating understanding through repeated revision, continuous questioning, and living the way taught in the particular environment. This process allows for the natural assimilation of knowledge. I have adopted this technique from completely different research areas, namely from the comparative religion studies and hermeneutic method developed by Dr. René Gothóni[77]. In the 1980s and 1990s, he lived with Buddhist monks in Sri Lanka and Orthodox monks in Mount Athos.

As an independent researcher without affiliation with academic institutions and working in English, which is not my native language, I used technical tools extensively to ensure the accuracy of the text. These tools include Google Docs, MS Word, Grammarly[78], Formula Generator[79], ChatGPT[80], and various search engines.

Nearly every sentence in the essay has been evaluated with ChatGPT's assistance, sometimes dozens of times, to fine-tune the grammar and coherence. My most used prompt has been: “Check grammar, facts, coherence, and give a list of improvement items: {text block}.” If suggestions were fine, I could continue and prompt: ”Rewrite the given paragraph.“ Typically, ChatGPT injects hyperbola and other naïve idioms into the text, which can be bypassed by asking for a formal tone in language or setting custom instructions for the ChatGPT application. But even then, generated text is rarely usable as it is because it contains a lot of tautology and, as some would say,

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[77] Rene Gothoni (researchportal.helsinki.fi)
[78] Grammarly (grammarly.com)
[79] Formula Generator (formula-generator.com)
[80] ChatGPT (openai.com)

‘soulless’ literary expressions. Manual work is required, and therefore, comprehension is guaranteed.

I then ensured that details aligned with known information in the field by reading books, listening to podcasts, and watching videos. For sections about TGD, I consulted Dr. Pitkänen by email and in weekly Zoom meetings, which often led to lengthy discussions, after which I revised the content.

With Large Language Models (LLM) like ChatGPT 4, my favorite way of interacting with it is to pass some text block I have written and prompt ChatGPT to discuss that topic with me. The goal is to create a coherent dialogue on the subject, which ensures that my understanding and ChatGPT’s “understanding” are on the same page. If ChatGPT seems to understand my point, I am on stable ground with the text. I take it as an indication that humans should also be able to understand it.

It is worth noting that ChatGPT advocates consensus in chats and often nags with alternative proposals. While this is generally acceptable, in cases where you want to doodle with new ideas and evaluate alternative non-mainstream theories, it produces time-consuming overhead.

I also ask ChatGPT for ideas on how to make concepts and narratives more accessible. Ideally, dialogue with ChatGPT speeds up learning about almost any topic. Without the help of ChatGPT, authoring this essay could have taken from a year to three, in my estimation, while now it took six months of my spare time.

There is also a limitation in working with new abstract theoretical ideas like in TGD. ChatGPT must be controlled and fed even the smallest details to produce coherent and factually correct content. TGD’s induction principle, spacetime surface, and the hyperspace with the Kähler action are not so common combinations of concepts. ChatGPT could not produce correct details from its intrinsic training set without my continuous guidance and review by experts like Dr. Pitkänen. This is the current limitation of ChatGPT 4 in 2023, but it might well be overcome in the future if the reasoning abilities of LLMs evolve as expected. Do they even give new concrete ideas on solving unification problems, we will see.

Interviewer – Writer's Box

My name is Marko Manninen. I am an independent researcher, essayist, and mesokosmos.com podcast host. I work in a recruitment business as a code architect and study perennial philosophy and modern science in my spare time. Physics-wise, I have worked on a gamma-ray scintillator 'unquantum' experiment with an American inventor and electrical engineer, Eric Reiter, and published a peer-reviewed article on that topic, in 2021[81].

Over the last few years, I have studied various aspects of theoretical physics related to unified theories in informal online study groups on the Discord server and by reading and watching freely available online material.

This article is based on countless discussions with Dr. Pitkänen about TGD and life in general. Since I am not teaching mathematical physics or using it in real life as a profession, rather than tedious calculations and equation derivations, my central interest is in an ontic understanding of the theory coupled with self-taught hermeneutic research methods.

I've been inspired by the works of American theoretical physicists Brian Greene[82] and Sean Carroll[83], who gave online lectures during the COVID-19 quarantine period, mainly concentrating on understanding the mathematical basis of modern fundamental physics. That material hit the middle ground on which lay people without a profession in academia or research centers can participate in citizen science study. Also, podcast interviews by Curl Jaimungal's Theories of Everything YouTube channel[84] and Closer To Truth by Robert Lawrence Kuhn[85] have been on my frequent watch list.

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81 Marko T. Manninen, Tandem Piercer Experiment, Journal of International and Finnish Methodology, Issue 2 (2021)

82 Your Daily Equation with Brian Greene (youtube.com)

83 The Biggest Ideas in the Universe with Sean Carroll (youtube.com)

84 Theories of Everything with Curt Jaimungal (youtube.com)

85 Closer To Truth with Robert Kuhn (youtube.com)

Acknowledgments

It goes without saying that the most noteworthy influence and help on the topic has been the tireless patient Dr. Matti Pitkänen—so much so that at times, I am unsure if I wrote the text of this essay or if he wrote it through me. I also want to thank high school physics instructor and adjunct professor Antti Savinainen for his kind and valuable help proofreading and commenting on my work.

Appendix 1: Core Terms

TGD is built upon a set of distinctive, interconnected foundational ideas that align closely with established principles in mathematical physics. This glossary aims to provide a brief yet comprehensive overview of these essential concepts. Roughly half of the terms presented are universal to the field, while the remaining are specific or tightly tied to TGD and flagged with an asterisk*. Many TGD terms are presented in more technical detail in Dr. Pitkänen's Holography article.[86]

3-surface*: In TGD, a 3-surface refers to a three-dimensional geometric object representing a state of the system at a particular point in time. A 3-surface is a set S in a higher-dimensional space where for every point $p \in S$, every neighborhood N of p intersects both the set S and its complement S^c in such a way that $N \cap S$ and $N \cap S^c$ are non-empty. This defines S as the boundary of a 3-dimensional volume in a higher-dimensional space, but without including the interior of that volume.

4-dimensional General Coordinate Invariance (4-D GCI)*: In TGD, GCI states that physical laws remain invariant under arbitrary 4-D coordinate transformations.

Action principle: The principle encapsulates the dynamics of physical systems. In TGD, action is augmented by the requirement of holography, likening spacetime surfaces to 'Bohr orbits' and deriving the system's equations of motion via variational calculus.

Adelic physics*: In TGD, adeles combine real and p-adic number fields into a unified framework, aiding in understanding quantum TGD.

Algebraic extension of rationales*: Refers to extending rational numbers by including roots of a polynomial, aiding in understanding number theoretical aspects in TGD.

[86] Matti Pitkänen, Holography and Hamilton-Jacobi Structure as a 4-D generalization of 2-D complex structure, October 2023 (researchgate.net)

Algebras: An algebra over a field is a vector space with a bilinear product. Lie and associative algebras are essential in theoretical physics for understanding symmetries, transformations, and physical phenomena. Lie algebras describe continuous symmetries, such as rotations and translations, while associative algebras are used in representation theory.

Anomaly: In QFT, an anomaly represents a break in symmetry when moving from a classical to a quantum system. Types include gauge anomalies, affecting theory consistency; global anomalies, altering system states and phase transitions; and gravitational anomalies, related to quantizing gravity. The term can also appear in other contexts, such as topological anomalies, associated with the topology of the space; conformal anomalies, occurring when scale invariance is broken; statistical anomalies, found in thermodynamics and phase transitions; and classical anomalies, which refer to unexpected behaviors in classical systems.

Arrow of time: The concept of time is often understood as moving in a specific direction, from past to future. This directional movement of time is closely related to the second law of thermodynamics, which states that the total entropy of an isolated system will inevitably increase over time. Entropy refers to the measure of disorder or randomness in a system, and this law implies that systems have a natural tendency to become increasingly disordered and less organized over time. Therefore, the directional flow of time is a consequence of this natural trend towards an increase in entropy.

Bohr orbit*: According to the Bohr model of the atom, these are specific paths around an atomic nucleus where electrons can travel without radiating energy. They represent specific energy levels of an electron in an atom. In TGD, 'Bohr orbit' refers to a 4-D surface in the 8-D imbedding space, analogous to Bohr's quantized orbits of electrons in an atom.

Boltzmann weights: These are specific factors in statistical mechanics that determine the probability of a system occupying a particular state at a given temperature. They are exponential terms involving the negative of the state's energy divided by the product of Boltzmann's constant and the temperature. Boltzmann weights are central to the partition function, allowing one to calculate various thermodynamic properties.

Branes: In string theory, branes (membranes) are multi-dimensional generalizations of point particles. They range from one-dimensional strings (1-branes) to higher-dimensional objects (p-branes, where p indicates the number of spatial dimensions). The fundamental particles and forces are seen as vibrations of these strings and branes, with their dynamics central to the theory's description of the universe. In TGD, a particle as a surface is a fundamental object.

Calculus: Calculus is a branch of math that studies rates of change and accumulation. It has two main branches: differential calculus, which deals with rates of change, and integral calculus, which deals with accumulation. Calculus is essential for understanding physics dynamics.

Causal Diamond (CD)*: A causal diamond represents a region of $M^4 \times CP_2$ defined by the intersection of the future and past light cones originating from a point, aiding in understanding geometric time and the flow of time in TGD. CD plays a central role in zero energy ontology, quantum measurement theory, and TGD-inspired theory of consciousness.

Cognitive representation*: In TGD, a number-theoretical discretization of geometric objects, such as spacetime surfaces, has interpretation as a mathematical correlate for cognition.

Coherence: A property of waves that maintains constant phase differences over time. This feature is essential in quantum mechanics to describe the behavior of quantum states. Essentially, phase coherence refers to the predictability of the phase of a wave at any given time, and it plays a significant role in explaining the way quantum states evolve over time.

Complex numbers: In mathematics, a complex number is a number in the form $a + bi$ where a and b are real numbers, and i is the imaginary unit. Complex numbers are used in physics like quantum mechanics, engineering, and many other fields.

Configuration space: This is the space of all possible system configurations. In TGD, configuration space has been termed the World of Classical Worlds, which encompasses all possible 'Bohr orbits' of 3-surfaces and thus all possible classical histories of the universe.

Conformal invariance: Refers to a type of symmetry where the shape of objects and the angles between points are preserved under transformations, such as rotation or reflection.

Conservation laws: This is a fundamental principle in physics stating that specific properties, such as energy, momentum, or electric charge, remain constant within an isolated system over time. Conservation laws stem from symmetries in nature and explain the behavior of physical systems.

Continuum/discretization: A continuum refers to a continuous set of values or points, while discretization is converting a continuum to a finite set of discrete values or intervals.

Convergence/divergence: Terms describing the behavior of sequences or series; convergence is the tendency to approach a limit, while divergence is the tendency to grow without bounds.

Coordinate systems: A framework using one or more numbers, or coordinates, to determine the position of points in a space uniquely. Types of coordinate systems include Cartesian, polar, and spherical.

Coordinate transformations: Rules and equations for converting coordinates of points between different systems. Examples include Cartesian to polar coordinates transformations, Galilean transformations in classical mechanics, Lorentz transformations in special relativity, and general coordinate transformations in general relativity.

Coordinates: Numbers or other elements ordered in a set, used to specify the location of a point in a space. For example, cartesian coordinates in a 2-D plane use two numbers to identify a point's position.

Cosmic strings*: In TGD, these are object-like structures with a 2-D M^4 projection analogous to string world sheets, playing a role in cosmology and particle physics.

Cosmological constant: A later attached and then removed term in Einstein's equations of general relativity representing a constant energy density filling space homogeneously. Nowadays, it is associated with dark energy, or more precisely, one contributor to it. In Planck units, the dimensionless value is on the order of 10^{-122} (based on Planck mission, 2018).

Coupling constants: Coupling constants are numerical parameters that determine the strength of particle interactions in quantum field theory. They are associated with specific interactions, such as those involving charged particles and the electromagnetic field in quantum electrodynamics, or quarks and gluons in quantum chromodynamics. These constants are essential for predicting the behavior of particles and fields in a wide range of physical systems.
$\boldsymbol{CP_2}$*****: Complex Projective 2-space (plane) is a complex manifold used in TGD to extend the structure of spacetime. It is a 4-dimensional space with complex properties, crucial for embedding the Standard Model of particle physics within TGD's geometric framework. CP_2 scale can be considered 10^4 times Planck length (10^{-35} m).

Dark matter/energy: Hypothetical forms of matter and energy believed to account for a significant amount of the observed gravitational effects in the universe, galactic scale, and acceleration of the universe expansion from the beginning of the Big Bang.

Degrees of freedom: The minimum number of independent variables needed to describe a dynamical system's state or configuration, such as position coordinates or thermodynamic variables like pressure and temperature.

Determinism: Holds that every event and state in the universe is determined by previous events and states and is governed by unchanging natural laws. Although this idea is a fundamental principle in classical physics, it becomes less straightforward in quantum mechanics, where outcomes are probabilistic.

Differential geometry: A mathematical discipline blending algebraic and geometric techniques to study curves and surfaces, especially in theories of relativity and many other areas of theoretical physics.

Dimensions: In physics and mathematics, dimensions refer to the minimum number of coordinates needed to specify any point within a mathematical space. Dimensions can be spatial, temporal, or more abstract.

Dirac equation: A relativistic wave equation describing the behavior of fermions, a class of particles that includes electrons, under the influence of quantum mechanics and special relativity. Formulated by Paul Dirac, it combines quantum theory and the theory of special relativity to explain the behavior of particles with spin-½.

Embedding*: The process of placing one geometric object within another, like situating a lower-dimensional space within a higher-dimensional space. In TGD, X^4 spacetime is embedded in a higher-dimensional space $H = M^4 \times CP_2$. H is called *imbedding space* in TGD to denote the X^4 relation as a spacetime 'inside' H.

Entanglement: In quantum mechanics, entanglement describes a unique correlation between two or more particles. A measurement of one entangled particle provides immediate information about its partner, irrespective of the distance separating them. This phenomenon underpins technologies like quantum computing and quantum cryptography while challenging classical theories that insist on locality.

Entropy: In thermodynamics, a greater number of microstates for a given macrostate signifies higher entropy, suggesting a macrostate's broader distribution and likelihood. Increased entropy is often popularized as a higher disorder. Information theory quantifies the amount of information gained when a signal is received in terms of entropy. Information is identified as a reduction of disorder, assuming that the state assignable to the receiver is maximally entropic before receiving the signal.

Extension of p-adic number field*: Refers to an extension of p-adic numbers induced by the roots of a polynomial, aiding in understanding number theoretical universality in TGD.

Extra dimensions: Dimensions beyond the familiar three spatial and one temporal dimension, proposed in various theories to explain phenomena or unify forces.

Feynman diagrams: Pictorial representations used in QFT to describe the behavior of subatomic particles. Created by physicist Richard Feynman, these diagrams simplify complex equations and calculations.

Fiber/bundle: In topology and geometry, a bundle comprises a base space and a fiber space, where each point in the base space has a corresponding unique fiber.

Field: In physics, a field is a physical quantity represented by a number or tensor, defined at every point in space and time. Examples include the gravitational field and the electromagnetic field.

Fundamental particles: Basic building blocks of matter and force carriers, including fermions, which make up matter, and mesons, which mediate strong interactions between baryons. The Standard Model describes seventeen particles, including quarks, leptons, and gauge bosons.

Galois confinement*: In TGD, a mechanism for forming bound states analogous to color confinement is based on Galois groups, which are algebraic extensions of rationales.

Galois group*: A group of permutations of algebraic extension of rationales relevant in TGD for understanding the algebraic structure of quantum states.

Gauge Theory: A type of field theory where the laws governing a field are unchanged (invariant) under continuous transformations known as gauge transformations. These transformations form a group, the gauge group, which characterizes the symmetries of the system. Gauge theories are fundamental in describing electromagnetic, weak, and strong nuclear forces in the framework of quantum field theory.

General Coordinate Invariance (GCI): The principle that the laws of physics should be invariant under any coordinate transformation, allowing them to be expressed consistently in all coordinate systems. In TGD, GCI causes 4-D information to be encoded on a 3-D boundary.

Geometrodynamics: A term used, especially by John Archibald Wheeler, to refer to the dynamics of the geometry of space and time, especially in general relativity, where the curvature of spacetime interacts with matter and energy. It is often associated with describing gravity geometrically and understanding spacetime dynamics.

Global energy problem: Refers to the challenge of defining global conserved energy in general relativity due to its curved spacetime, which not only makes traditional notions of energy conservation problematic but also all symmetries in curved dynamic (expanding, undulating, radiating) spacetimes.

Grand Unified Theories (GUTs): Theories in particle physics that attempt to unify the three fundamental forces of the Standard Model (electromagnetism, the weak force, and the strong forces) into a single unified field.

Group Theory: A branch of mathematics exploring the algebraic structures known as groups, which are sets combined with operations satisfying particular properties. In physics, group theory is linked to symmetry and conservation laws.

Hadron physics: A specialized area within particle physics that studies hadrons, which are particles subject to strong nuclear force and the early universe's conditions. Hadrons are composite particles of quarks and are categorized into baryons (like protons and neutrons) and mesons (made of quarks and antiquarks).

Hierarchy of Planck constants*: TGD proposes multiple values of Planck's constant, explaining phenomena like dark matter.

Higgs mechanism: The Higgs mechanism is a process in the Standard Model of particle physics that explains how particles acquire mass. It proposes the existence of a pervasive field, the Higgs field, and particles acquire mass based on their interaction with this field. The strength of a particle's interaction with the Higgs field determines its mass. The Higgs boson, discovered in 2012, is the particle associated with the Higgs field and serves as evidence for this mechanism. It is replaced by p-adic thermodynamics in TGD.

Hilbert space: In quantum mechanics, a Hilbert space is a complex vector space with a potentially infinite dimensionality, equipped with an inner product. This structure allows for the definition of length and angles within the space. It serves as the fundamental mathematical framework to describe quantum states, where each point in this space represents a possible state of a quantum system. The infinite-dimensional nature of Hilbert spaces is crucial for encompassing the vast range of states in quantum systems, and the inner product facilitates computations of probabilities and expectation values, key for making predictions in quantum theory.

Holography*: Some theories suggest that the universe is a 3D projection of the information that is encoded on the 2D boundary of the universe. This idea is based on the laws of thermodynamics and quantum mechanics, which suggest that the information content of the universe is finite and can be represented on the boundary. The holographic principle has important implications for our understanding of black holes and the nature of space and time, and it is an active area of research in cosmology and theoretical physics. Holography in TGD posits that the information on a 3-surface almost entirely dictates the 4-D spacetime surface 3-dimensional data. A 3-surface can either be a boundary of a 4-surface in H at the opposite ends of a causal diamond or a light-like interface between regions of spacetime surface with Euclidian and Minkowskian signatures (light-like partonic orbit). These 3-surfaces provide holographic data including the induced metric and other inherited fields from H, along with data about fermionic dynamics. The dynamics of the 4-surface are directed by the extremization of action, typically the sum of the Kähler action and volume term.

Quantum states and observables, defined by the symmetries of the 3-surface configuration space or World of Classical Worlds, are integral to this principle.

Holonomy*: In TGD, it refers to the transformations a state undergoes when transported along a loop in imbedding space, spacetime, or in the configuration space (World of Classical Worlds).

Hyperbolic 3-space H^3*: A 3-dimensional space of constant negative curvature, relevant in TGD for understanding geometric and topological properties of spacetime.

Hyperspace: A term often used to describe dimensions or spaces beyond our familiar 3-dimensional space. Various theories use it to explain phenomena or concepts that require more than three spatial dimensions.

Imaginary numbers: Numbers that can be written as a real number multiplied by the imaginary unit i, where $i^2 = -1$. They are fundamental in complex analysis and have crucial quantum mechanics and electrical engineering applications.

Imbedding space*: The 8-dimensional space $H = M^4 \times CP_2$, where the 4-D spacetime surfaces of TGD are embedded.

Induction*: In TGD, induction refers to the process of inducing (projecting) the geometric properties of spacetime surfaces from the higher-dimensional space in which they are embedded.

Isometry: In mathematics, isometry is a type of transformation that preserves the distances between any two points in space. This means that if you have two points, A and B, in the original space, and you apply an isometry transformation to the space, the distance between points A and B in the transformed space will be the same as the distance between them in the original space.

Kaluza-Klein Theory: This is an early attempt to unify electromagnetism and gravity by introducing a higher-dimensional spacetime. Kaluza-Klein theory posits that our familiar 4-dimensional spacetime is embedded within a 5-dimensional spacetime, where the fifth dimension is compactified (curled up) to a small size. The extra dimension allows for the geometrization of electromagnetism alongside gravity, but the theory faced difficulties in incorporating the other interactions and particle properties.

Kähler action: This appears besides volume action in the action principle in TGD, determining the dynamics of the spacetime surface as associated induced fields, and is determined by the Kähler geometry of the space in which spacetime surfaces are embedded.

Kähler electric and magnetic field*: Fields arising from the Kähler geometry of the embedding space in TGD play a role analogous to electromagnetic fields in standard physics but within the geometric framework of TGD.

Kähler geometry: Kähler geometry is characterized by a Kähler metric, which is a Hermitian metric defining the Kähler form as a differential geometric representation of an imaginary unit. Kähler geometry is also accompanied by symplectic geometry.

Lagrange/Hamiltonian: Classical mechanics uses formalisms such as the Lagrangian and Hamiltonian to represent the dynamics of physical systems. The Lagrangian is the difference between the kinetic and potential energy, while the Hamiltonian is the total energy. These formalisms are widely used in physics and engineering to model and analyze various physical phenomena.

Light cone: The light cone is a graphical representation in special and general relativity that shows the path of light in spacetime emanating from a single event. It helps determine causality and provides a tool to understand the structure of spacetime. Events within the light cone can have a causal relationship with the originating event, while those outside cannot.

Local causality and simultaneity: Rooted in Einstein's theory of relativity, local causality postulates that an event's outcome can only be influenced by occurrences within its past light cone. Simultaneity, or the notion that two events happen simultaneously, is not an absolute concept but depends on the observer's frame of reference.

Loop Quantum Gravity (LQG): A theoretical framework that attempts to reconcile general relativity principles with quantum mechanics by positing that spacetime itself is quantized, usually visualized as a spin network of interconnected loops.

M^4: Represents the four-dimensional Minkowski space, a geometric setting for the spacetime physics of special relativity. Note: number 4 does not refer to the power of M but indicates the number of dimensions from which one is time and three are spatial.

$M^8 - H$-duality*: A concept in TGD linking geometric descriptions (H) and algebraic descriptions (M^8, an octonionic Minkowski space), akin to the impulse-position duality, providing two interchangeable viewpoints of TGD physics.

Magnetic body*: A hierarchy of magnetic flux tubes in TGD, a communicator between ordinary matter and dark matter. It also plays a vital role in TGD's theory of consciousness and biology, explaining the elusive nature of dark matter detection. The magnetic body is viewed as a self-organizing entity that interacts with bio-systems via dark photons, affecting their behavior and guiding their evolution.

Manifold: In mathematics, a manifold is a space that is locally similar to a linear space. Manifolds are used in physics to describe a wide range of spaces, including spacetime in general relativity.
Many-sheeted spacetime*: In TGD, spacetime is visualized as having many sheets, each corresponding to different physical phenomena. Many-sheetness is due to the variational principle and its solution forming the spacetime surface.

Maxwell action (and others): In classical electromagnetism, the Maxwell action is the integral over spacetime of the Lagrangian density, which is constructed from the electromagnetic field tensor. The action principle is a broader concept that finds use in various areas of physics, including the Einstein-Hilbert action in general relativity and the Lagrangian or Hamiltonian formulations in quantum mechanics. Yang-Mills' action extends the Maxwell action to include non-abelian gauge fields, the foundation for QFT describing strong and weak nuclear forces.

Measurement problem: An unresolved issue in quantum mechanics that deals with transitioning from a system's superposition of states to a single observed state upon measurement. It highlights the contrast between quantum states' probabilistic nature, as described by the wave function, and the definitive outcomes seen in experiments. A key aspect involves understanding and justifying the Born rule, which connects the probability of an outcome to the square of the wave function's amplitude. Addressing this problem has led to various theories, such as the Many-Worlds, Bohmian Mechanics, and the Copenhagen framework, each offering different explanations for this transition.

Metric: In mathematics and physics, a metric defines the concept of distance between any two points in each set. It is a key concept in studying spaces and geometries, underpinning theories like general relativity.

Metric signature: The metric signature is a characteristic of a metric tensor in geometry and physics, particularly in the theory of relativity. It indicates the difference between the number of positive and negative terms in the diagonal of the metric tensor when brought to diagonal form. Common signatures include (3,1) or (-+++), used in general relativity to represent one time-like and three space-like dimensions, and (4,0) or (++++), used in Euclidean space. The signature is fundamental for studying spacetime and affects the behavior of distances and angles within the geometry.

Monopole flux tubes*: In TGD, they are structures carrying magnetic monopole fields, crucial for understanding particle physics and interactions across different scales, including cosmological and biological phenomena.

Negentropy Maximization Principle (NMP)*: A principle in TGD suggesting systems evolve to maximize negentropy as a measure for the amount of conscious information (not the negative of thermodynamic entropy), linking to a TGD-based theory of consciousness and consistent with the second law of thermodynamics.

Non-Euclidean geometry: Geometry that differs from classical Euclidean geometry is essential in formulating Einstein's general relativity.

Number Theory: A branch of mathematics with applications in theoretical physics, especially in fields like string theory, where properties of integers can have physical interpretations.

Observable: In physics, an observable corresponds to a measurable property or quantity of a phenomenon or system.

Octonion: Even further extended than quaternions, octonions have one real part and seven imaginary parts. They are used less frequently but appear in some advanced theories, such as string theory.

p-Adic mass calculations*: In TGD, a method for calculating particle masses using p-adic number theory significantly aligns with observed masses of various particles.

p-Adic number: A type of number system that extends beyond the real numbers, useful in number theory and TGD for modeling hierarchies and quantum states, forming a bridge between the geometric and the arithmetic. Note the naming convention in TGD: A is capitalized in ‘p-Adic’ if p-adic is written as the first word in a sentence.

p-Adic number field: Completions of the rational numbers using p-adic norms.
p-Adic physics*: A framework in TGD using p-adic number theory to understand quantum states and transitions, leading to a fractal hierarchy of scaled variants of physics across various fields.

p-Adic thermodynamics*: An approach in TGD to understand thermodynamic properties using p-adic number theory, providing a way to calculate masses of elementary particles and offering a potential cognitive representation supplied by Nature.

Partonic 2-surface*: Two-dimensional surfaces in TGD for constructing spacetime surfaces and understanding the behavior of elementary particles.

Path integral: In quantum mechanics, the path integral formulation extends the action principle to a method of quantizing fields. It replaces the classical notion of a single, unique trajectory for systems with a sum over all possible trajectories to compute a scattering amplitude. Richard Feynman primarily developed this method.

Perturbation Theory: A mathematical technique used to approximate the solution of a complex problem based on the known, simple solution. QFT approximates the behavior of quantum systems by expanding around a known, simple solution.

Phase: In oscillatory systems, phase refers to a particular point in the time cycle of a periodic function. It is often measured in degrees or radians.

Planck constant: Represented by h, this fundamental constant appears in quantum mechanics. It sets the scales for quantized phenomena, occurring in equations that describe the energy levels of atomic orbitals, the quantization of angular momentum, and the energy of photons. Its value is approximately $6.62607015 \times 10^{-34} \frac{m^2 kg}{s}$.

Platonic solids: These are the only five regular polyhedra that exist in three-dimensional Euclidean space—tetrahedron, hexahedron (cube), octahedron, dodecahedron, and icosahedron. Each has faces of identical shape, size, and angle. They have been explored for their aesthetic and geometric properties and are sometimes considered in theories attempting to describe fundamental structures in nature.

Point-particle: In physics, a point particle is an idealized object representing a particle with mass but no spatial extent. It is often used for simplicity in calculations.

Preferred extremals*: In TGD, a preferred extremal refers to a solution of the field equations that minimizes or extremizes the action satisfying holography so that only the data about the 3-D surface but not about its 4-D tangent space, determine the 4-surface.

Projection/induction*: In TGD, the mapping of higher-dimensional structures onto lower-dimensional subspaces, like 3-surfaces, determines how properties like geometry and fields manifest in the theory. Also referred to as induction.

Quantization: A cornerstone of quantum mechanics, quantization involves converting a classical system's continuous variables into a set of discrete eigenvalues. This transition occurs at three levels. First quantization applies to individual particles in non-relativistic quantum mechanics, describing phenomena like quantized energy levels that apply to a single particle. Second quantization extends to quantum fields, capturing phenomena like particle creation and annihilation. Third quantization is a speculative idea focusing on quantizing the universe's wave function in the context of quantum cosmology.

Quantum: Refers to the smallest indivisible unit or amount of physical properties such as energy. In physics, it is a fundamental concept describing the behavior of matter and energy on the smallest scales.

Quantum biology: Examines the role that quantum mechanics may play in biological processes. For example, quantum tunneling facilitates some enzymatic reactions, and quantum coherence improves the efficiency of photosynthesis.

Quantum Chromodynamics (QCD): This is the theory in the Standard Model of particle physics that describes the strong force and the interactions between quarks and gluons. It is a quantum field theory formulated using non-abelian gauge theories, specifically the group $SU(3)$.

Quantum criticality: Describes the properties of a system right at the transition between different quantum phases. At this point, the system displays scale-invariant behavior, meaning that its properties are the same at any length scale.

Quantum Electro Dynamics (QED): A quantum field theory that describes how light and matter interact. QED combines the principles of quantum mechanics and the theory of electromagnetism.

Quantum Field Theory (QFT): A theoretical framework combining classical field theory, quantum mechanics, and special relativity to explain the dynamics of quantum particles and fields. It is the basis for understanding particle physics, including the Standard Model.

Quantum gravity: A framework aiming to reconcile general relativity with quantum mechanics to formulate a quantum theory of the gravitational field.

Quantum numbers: Sets of numerical values that provide a complete description of the quantum state of a particle, categorizing properties such as energy levels, angular momentum, and magnetic spin.

Quantum state/jump: Quantum state refers to the state of a quantum system, described by a vector in a Hilbert space. A quantum jump is a change from one quantum state to another.

Quaternion: An extension of complex numbers, quaternions consist of one real and three imaginary parts. Quaternions are used in computer graphics, control theory, and other areas requiring spatial rotations.

Real numbers: Numbers that can be located on the number line, including both rational and irrational numbers. They form a subset of complex numbers and are fundamental in all mathematical and physical disciplines.

Renormalization: A technique in QFT, the theory of elementary particles, where infinite (or undefined) results from calculations are adjusted in such a way as to make them finite. It is a standard tool for dealing with the infinities that arise in QFT.

Riemann surface: A manifold endowed with complex structure, allowing for the definition of holomorphic functions. Riemann surfaces are used to explore complex function theory and appear in the mathematical formulation of string theory, where they describe the string's world sheet.

Rigid body: In a theoretical context, a ‘rigid’ object is an idealization that assumes the object does not deform under external forces or torques. In this model, all distances between particles within the object remain constant, regardless of the forces applied to it. This is a simplification used in many areas of physics, particularly in mechanics, to make problems more tractable. In reality, no material is perfectly rigid; all materials will deform to some extent under sufficient force. Note, that solid is a state of matter, while not all solids are rigid.

Scales (micro, meso, macro): These are the lenses through which physical phenomena are viewed. The microscale involves atomic and subatomic interactions governed by quantum mechanics. The mesoscale encompasses complex systems like biological cells and materials, described by statistical mechanics. The macroscale includes larger structures like planets and galaxies, where gravitational interactions dominate.

Scattering amplitudes: Quantities referring to the mathematical representations of the likelihood of particle interactions or reactions occurring. They are key in determining the probability of particle reactions in quantum mechanics and particle physics.

Schrödinger equation: A fundamental quantum mechanics equation that describes how a physical system's wave function changes over time. It serves as the mathematical foundation for describing the time evolution of quantum systems and allows physicists to predict future states based on initial conditions.

Small state function reduction (SSFR) and big state function reduction (BSFR)*: These terms refer to state function reductions in TGD, driving the system's dynamics. SSFRs maintain the arrow of geometric time, defining a flow of consciousness and associating an element of free will. BSFRs are triggered when the system is perturbed, changing both the state and the arrow of geometric time, linking to concepts like ‘universal death’ and ‘reincarnation’ with a reverse arrow of time.

Spacetime: A concept in physics that combines the three dimensions of space with the one dimension of time into a single four-dimensional continuum, especially in the theory of general relativity.

Spacetime as 4-surface*: In TGD, spacetime is envisioned as a 4-dimensional surface in an 8-dimensional space $M^4 \times CP_2$, allowing for a more detailed description of physical phenomena across scales. It distinguishes itself from general relativity by enabling non-trivial topologies and interactions.

Spacetime sheets*: In TGD, spacetime sheets are 4-dimensional surfaces embedded within the 8-dimensional hyperspace. They represent the fundamental building blocks of the physical universe and are responsible for various phenomena such as particles, fields, and interactions.

Spin/isospin: Quantum properties of elementary particles. Spin is the intrinsic angular momentum, while isospin is a quantum number related to the strong and weak interactions.

Standard Model (particle physics): The prevailing theory in physics which describes three of the four fundamental forces (electromagnetic, weak, and strong) and classifies all known elementary particles.

Standard Model (cosmology): The cosmological framework known as Lambda CDM (Cold Dark Matter) based on general relativity, describing the universe's evolution, including the Big Bang, cosmological constant, cold dark matter, and the distribution of galaxies.
State reduction/wave-function collapse: The process in quantum mechanics where a wave function—describing a system in a superposition of states—collapses to a definite state upon measurement.

String model: In string theory, a string is a one-dimensional object with length but no other dimension—a candidate for the primary entity of all matter and forces. String models typically require extra dimensions (usually 10 or 11, even 26) to accommodate their mathematical structure.

$\boldsymbol{SU(3) \times SU(2) \times U(1)}$: A product of three mathematical groups representing a symmetry structure. In particle physics, $SU(3)_C$ (color charge) corresponds to the symmetry of the strong interaction, $SU(2)_L$ encapsulates the weak interaction, and $U(1)_Y$ (hypercharge) stands for electromagnetism, which led to the prediction of the photon and the Z boson (after electroweak symmetry breaking), which mediate electromagnetic and weak forces, respectively.

Super-Kac-Moody algebra (extended)*: Infinite-dimensional algebraic structures in TGD, extending the super-Kac Moody algebras of string models and associated with the World of Classical Worlds' holonomies.

Supergravity: Supergravity is an extension of general relativity that incorporates the principles of supersymmetry, a symmetry that relates bosons and fermions. It is formulated in curved spacetime and seeks to unify gravity with other interactions. Supergravity can be seen as a classical limit of some versions of string theory and has connections to other unification attempts, such as M-theory.

Super particles: Hypothetical particles in supersymmetry theories, each corresponding to a known particle in the Standard Model. Examples include selectrons, squarks, neutralinos, charginos, and the gravitino.

Supersymmetry (SUSY): A theory in which each fermion has a bosonic superpartner particle and vice versa, aiming to resolve various issues in particle physics, like hierarchy problem, which concerns the large discrepancy between the weak force scale and the Planck scale, dark matter, grand unification, and quantum gravity.

Superposition: In quantum mechanics, superposition refers to the combination of all possible states a quantum system could be in. The system simultaneously exists in multiple states, and its actual state is only determined when a measurement is made.

Symmetry breaking: Occurs when a system in a symmetrical state transitions to a less symmetrical state. In the context of the Higgs mechanism and electroweak symmetry breaking, this process is essential for understanding mass acquisition in elementary particles. Initially, gauge bosons (like W and Z bosons) are inherently massless due to the preservation of gauge symmetry, which ensures uniformity and symmetry in the laws governing these particles. However, when a field invariant under this gauge symmetry $SU(2) \times U(1)$ attains a non-zero vacuum expectation value, it signifies the breaking of the electroweak symmetry. This symmetry breaking alters the interaction dynamics of the gauge bosons with the Higgs field, resulting in them acquiring mass. Without such symmetry breaking, these bosons would inherently remain massless, as their massless nature is inherently linked to the unbroken gauge symmetry.

Symmetry/invariance: Symmetry is the property of a system or object that remains unchanged under specific transformations, such as rotations, translations, reflections, or scaling. Global symmetries in physics lead to conservation laws, including energy, momentum, and electric charge. Symmetry is a fundamental concept in mathematics and physics and a powerful tool for understanding the laws of nature.

Symplectic geometry: A branch of mathematics, specifically in differential geometry and topology, which focuses on the study of symplectic manifolds. These are smooth manifolds equipped with a closed, non-degenerate, skew-symmetric bilinear form called a symplectic form. Originally developed from the principles of classical mechanics, particularly from Hamiltonian systems.

Tensor: A generalization of vectors and matrices, tensors are multi-dimensional arrays of quantities that transform under coordinate changes. Tensors are used in physics for describing complex relationships between different physical quantities.

Tensor calculus: An extension of vector calculus to multi-dimensional spaces, dealing with quantities known as tensors.

Theory of Everything (ToE): A hypothetical theory that thoroughly explains and links all known physical phenomena, aiming for a unified description of all fundamental forces and particles. One of the first ToEs was researched by Gunnar Nordström, Albert Einstein, David Hilbert, Gustav Mie, and Oskar Klein, but they were far ahead of their time because not all fundamental forces and fundamental particles were known until then.

Time evolution: Describes how a system's wave function evolves in quantum systems, governed by the Schrödinger equation.

Time reversal*: TGD's concept of time reversal incorporates both geometric and subjective time, distinguishing between traditional time reversal and thermodynamic time reversal, linking to state function reductions, and redefining the arrow of geometric time in a unique framework.

Topology: A branch of mathematics studying the properties of space under continuous transformations. In physics, topology helps understand properties like continuity, compactness, and convergence, including the study of exotic states of matter and QFT.

Transformation: In mathematics, a transformation refers to the process of altering the position, size, or shape of points in a space. This process is governed by specific rules or functions. Common types of transformations include translations (shifting points in a space), rotations (turning points around a fixed axis), scaling (changing the size while preserving shape), and reflections (flipping points across a line or plane). In the context of group theory, these transformations can often be represented and analyzed using group-theoretic notation, as they form mathematical groups with properties like closure, associativity, identity, and invertibility. Transformations are integral to studying geometrical properties and are widely applied in various branches of mathematics and physics.

Twistor field space: A complex vector space in theoretical physics, used in twistor theory to provide an alternative description of spacetime and particle interactions. It represents light rays in Minkowski spacetime as points in this complex space. Twistor space encodes both the position and momentum of particles, simplifies certain field equations from gauge theory and general relativity into algebraic forms, and involves wavefunctions as functions of twistors, which is particularly useful in quantum field theory for streamlining calculations of scattering amplitudes and uncovering hidden symmetries in particle interactions. In TGD, the twistor space is extended to a 12-D space $T(M^4) \times T(CP_2)$, and a geometrization of the twistor field similar to that for the Standard Model gauge fields is carried out.

Twistor lift/twistorization*: A reformulation process in TGD representing twistor space as a 6-D surface $T(X^4)$ in $T(M^4) \times T(CP_2)$, addressing the limitations in the traditional twistor approach and uniquely situating TGD through an altered 6-D Kähler action, linking to the cosmological constant.

Ultrametricity*: A property aligning with TGD's hierarchical and geometric foundations, standard in p-adic analysis and hierarchical clustering, emphasizing a more robust version of the triangle inequality in a metric space.

Uncertainty Principle: In quantum mechanics, the Heisenberg Uncertainty Principle asserts a fundamental limit to the precision with which pairs of a particle's physical properties, such as position and momentum, can simultaneously be known.

Unification: An attempt to form a theory that combines different fundamental interactions into a singular framework, such as the electroweak theory, GUTs, or ToE.

Vacuum degeneracy: Refers to the multiple energetically equivalent vacuum states in QFT. This phenomenon leads to effects like spontaneous symmetry breaking and can result in the emergence of domain walls, solitons, and other topological defects.

Variational Principle: A principle used in physics to find the physical states of a system by minimizing or maximizing a function, often the action. It is a fundamental principle underlying the formulation of many physical theories, including quantum mechanics and general relativity.

Vector: A mathematical object characterized by both magnitude and direction. Vectors are used in physics to describe quantities like velocity, force, and acceleration.

World equation/master formula: In the context of the Standard Model, the world equation encapsulates the interactions among fundamental particles and forces. It is expressed through a Lagrangian density encompassing terms for electromagnetic, weak, and strong forces, interactions between matter and forces, and dynamics of the Higgs field. This compact representation encodes a wealth of information regarding the underlying structure and dynamics of the particle physics realm. Theory of Everything would potentially include gravity in the same master equation.

World of Classical Worlds (WCW)*: The set of all possible 3-dimensional spacetime surfaces in TGD, each termed a 'world,' representing classical evolutions within an 8-dimensional embedding space, with holography guiding the transition from 3-D to 4-D surfaces.

World of Classical Worlds symmetries*: These are symmetries in the WCW in TGD required for the quantum states and dynamics of the theory, highlighting a fractal hierarchy of subalgebras, leading to a hierarchy of symmetry breakings.

Wormhole contacts*: In TGD, wormhole contacts are considered elementary particle building blocks, having a size related to the CP_2 scale and Euclidean signature metric. Not to be confused with a tunnel between two black holes or other points in spacetime.
X^1-X^4: These symbols represent coordinates in a one to four-dimensional spacetime, where dimensions may be a mixture of spatial and temporal types.

Zeno effect: A quantum mechanical effect where a system's evolution can be halted by measuring it frequently.

Zero Energy Ontology (ZEO)*: A framework in TGD emphasizing zero-energy states within a causal diamond, offering a unique arrow of time, and tying to the TGD-inspired theory of consciousness, as the flow of consciousness corresponds to a sequence of quantum measurements in this ontology.

Zero-energy state: Also known as the ground state, the lowest possible energy state in a quantum system, with a zero-point energy that leads to phenomena like the Heisenberg Uncertainty Principle. Contrary to the name, it does not mean the ground state energy is zero.

Appendix 2: Timeline

Topological Geometrodynamics has developed over several decades, involving the gradual refinement of its key ideas and concepts. Here is a brief history timeline:

- **1970s**: TGD traces its origins back to the end of 1977, when Dr. Matti Pitkänen got the first core ideas for the theory. This theory aimed to solve the problem of global conservation laws in general relativity and unify electromagnetism and gravity through a submanifold induction principle. At this stage, the theory had not yet specified the required compact space, but any compact space could solve the problem.
- **1980s**: The initial ideas evolved into the first publication in 1981, focusing on geometroelectrodynamics[87]. Dr. Pitkänen's thesis developed into a theory of everything, conceptualizing a hyperspace H as a Cartesian product of Minkowski space M^4 and a compact manifold CP_2. The thesis was submitted in 1982 and published in 1983 in the International Journal of Theoretical Physics, with David Finkelstein as the editor. Finkelstein had handed the theory to John A. Wheeler, who suggested the name 'Topological Geometrodynamics' in a referee report for Dr. Pitkänen's thesis article[88] on TGD. Positive intervention by Wheeler was a shocking surprise and forced thesis examiners and opponents to take the dissertation seriously. The World of Classical Worlds concept, a space of 3-surfaces in an 8-dimensional imbedding space, emerged after Dr. Pitkänen's doctoral thesis around 1985. The original term was 'configuration space.'
- **1990s**: The early 1990s saw the formation of Zero Energy Ontology, a central aspect of TGD for describing physical phenomena at both classical and quantum levels. The notion of 'preferred extremals,' expressing the holographic principle and initially termed as the 'absolute minimum of Kähler action,' also emerged. The decade was characterized by advancements in understanding

[87] Matti Pitkänen, Geometroelectrodynamics, International Journal of Theoretical Physics (1981)
[88] Matti Pitkänen, Topological Geometrodynamics, International Journal of Theoretical Physics (1982)

quantum criticality and its impact on Kähler coupling strength. The first articles on p-adic physics in TGD were published in 1994[89] and 1995[90].

- **2000s**: TGD continued to explore the relationship between classical and quantum properties. This period marked the integration of number-theoretical ideas into TGD, particularly after 2005, including the p-adic length scale hypothesis and the hierarchy of Planck constants. Dr. Pitkänen started a blog[91] to publish his ideas and developments in TGD. Twistorization became an integral part of the TGD at the end of the decade. The motivations for twistors were the successes of the twistor formulation in gauge field theory, especially in N=4 SUSY. They made possible some incredible computational feats, revealed relatively simple structures, and offered a promising alternative to Feynman diagrams.
- **2010s**: This decade saw the ongoing development of number-theoretical concepts and the $M^8 - H$-duality within TGD. It is a generalization of the wave mechanics impulse-position duality, inspired by the reduction of quantum TGD to a generalization of wave mechanics, which is induced by replacing assumed point-like particles in the standard relativity and QFT with 3-surfaces. In 2016, a comprehensive, over a thousand-page revised book about TGD was published by Bentham Books[92]. In September 2019, correspondence between Dr. Pitkänen and Marko T. Manninen began, leading to a three-part interview podcast about TGD and the Quantum Mechanical worldview in Finnish language[93]. After over 1,000 emails and dozens of meetings later, this collaboration resulted in more joint work, including the essay being discussed.
- **2020s**: Current TGD research focuses on refining and expanding the theory's core principles. Applications in cosmology, astrophysics, particle physics, and quantum gravity are being pursued, focusing on dark matter and quantum coherence in astrophysical and biological scales.

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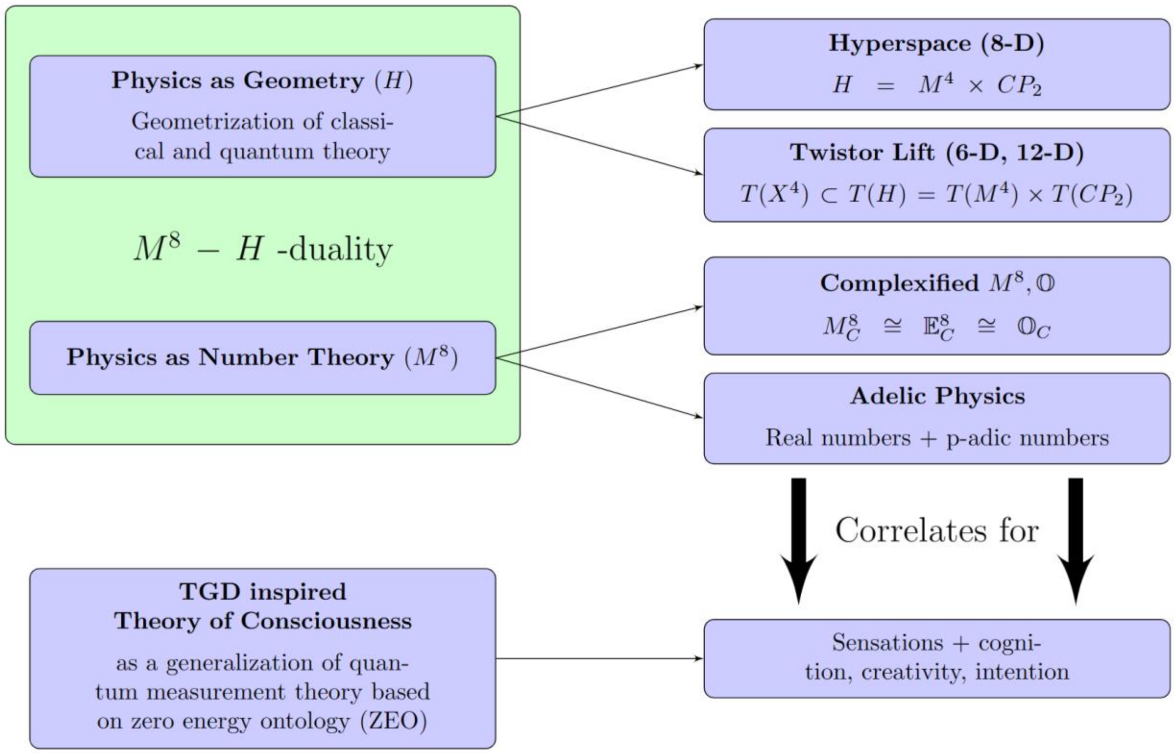
89 Matti Pitkänen, p-Adic Field Theory limit of TGD is free of UV divergences (1994)
90 Matti Pitkänen, p-Adic TGD: Mathematical Ideas (1995)
91 TGD diary (matpitka.blogspot.com)
92 Matti Pitkänen, Topological Geometrodynamics: Revised Edition (2016)
93 Mesokosmos, Kvanttikietoutumia ja koherenttia maailmankuvaa etsimässä, 1–3, 17 March 2020 (mesokosmos.com)

Appendix 3: Conceptual Maps

TGD – Big Picture



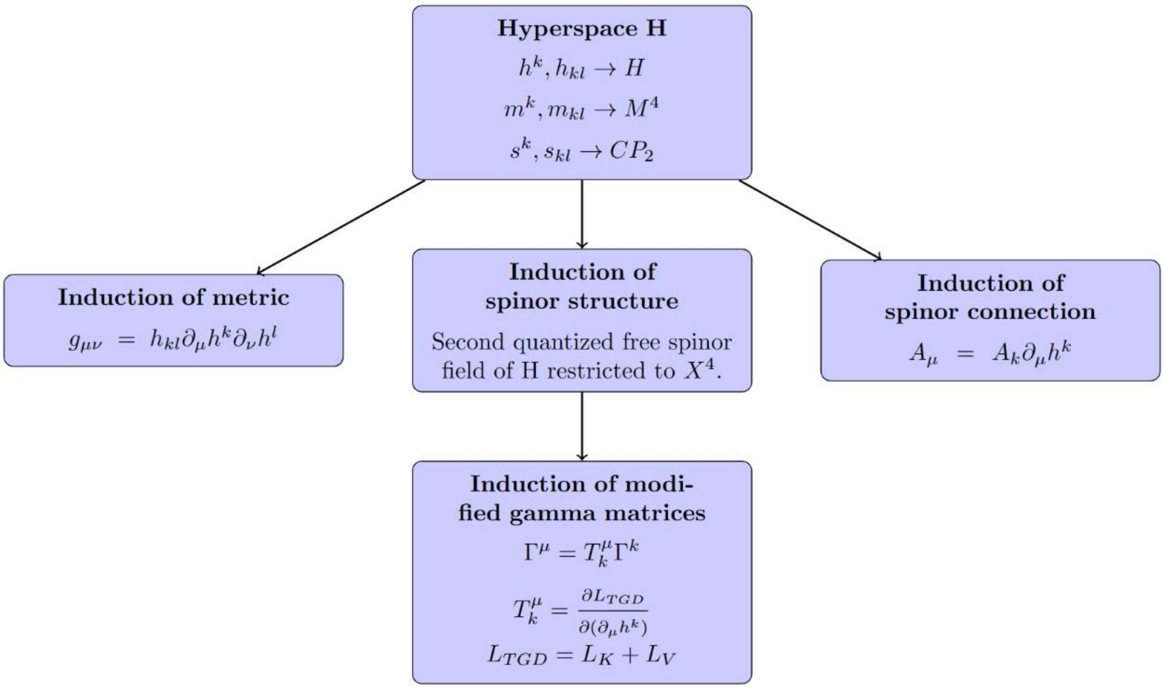
This diagram provides a holistic view of TGD theory. Physics as Geometry aspect illustrates the geometrization of classical and quantum theories, underscoring TGD's approach to unifying physics through geometric constructs. It connects to two key concepts: 1) Hyperspace H, highlighting the 8-dimensional backdrop space of TGD and 2) Twistor Lift, demonstrating the extension of the 4-dimensional spacetime X^4 into 6-dimensional spacetime $T(X^4)$ and hyperspace geometry H into the 12-dimensional twistor space $T(H)$.

Physics as a Number Theory aspect points to integrating number theory into physics. It leads to complexified M^8, $\mathbb{O}$ indicating the complexification of eight-dimensional space, correlating with octonions and Adelic physics combining real and p-adic numbers.

Geometry gives the position and Number theory the impulse in the impulse-position duality relation between the two aspects of TGD.

Adelic physics correlates to cognition and TGD inspired theory of consciousness within the same framework.

TGD – Induction



This diagram presents the induction processes within TGD framework. Various mathematical structures are induced from Hyperspace H. Upper and lower indices k, l refer to the components in H throughout the notation.

Three primary inductions are depicted:

1) The Induction of Metric, where the metric $g_{\mu\nu}$, is defined in terms of partial derivatives of the hyperspace coordinates.
2) The Induction of Spinor Structure, representing the restriction of the second quantized free spinor field of Hyperspace H to the Spacetime Surface X^4.
3) The Induction of the Spinor Connection, which involves the induction of the spinor connection A_μ through partial derivatives.

Finally, the diagram shows the Induction of Modified Gamma Matrices as a subsequent step, derived from the induced spinor structure. A new set of gamma matrices Γ^μ are transformed from the standard gamma matrices Γ^k with a T^μ_k tensor.

TGD – Physical Interpretation

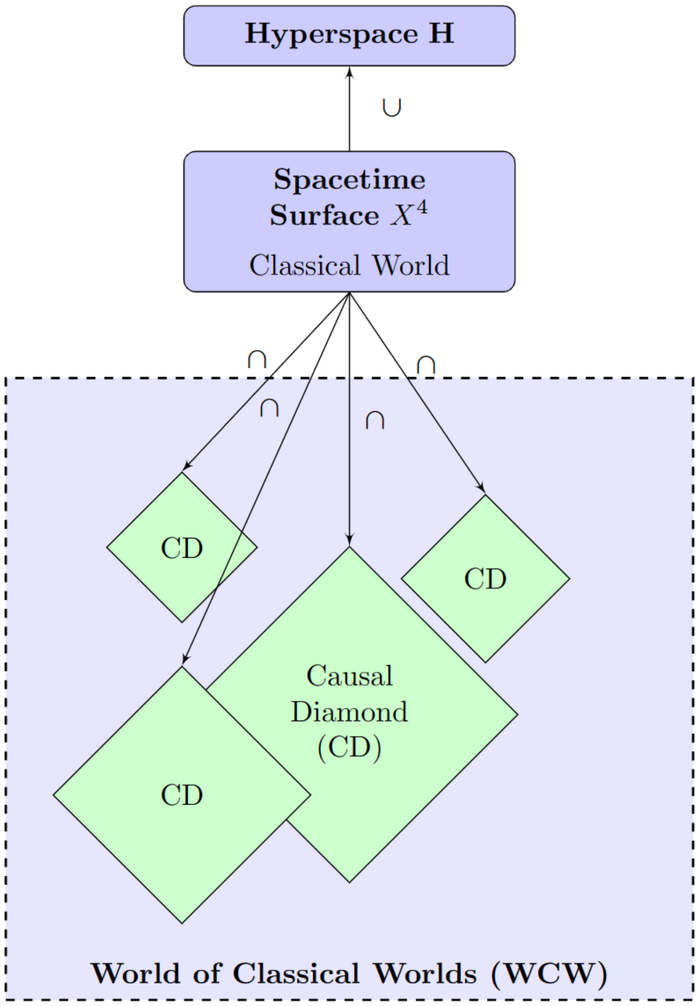
Geometrization of standard model fields and gravitation	**Topologization**
Induced spinor connection of CP_2 → Electroweak gauge potentials	Replacement of point-like particle with 3-surface → Partonic 2-surfaces as wormhole throats
Projections of Killing vectors of color isometries of H → Gluonic gauge potentials	Topological explanation of family replication (generations) phenomenon
Induced metric of H → Gravitational fields	Kähler magnetic monopole flux tubes from the homology of CP_2 → Particle-like object as a closed monopole flux tube with fundamental fermions at wormhole throats
Second quantized free spinor field of H → Fundamental fermions appearing as building bricks of all elementary particles	

On the left, the Geometrization aspect contains concepts from the Standard Model fields and gravitation to TGD constructs. This includes translating induced spinor connections, projections of Killing vectors, and induced metrics into electroweak gauge potentials, gluonic gauge potentials, and gravitational fields, respectively. The concept of second quantized free spinor fields is also related to fundamental fermions.

On the right, the Topologization aspect highlights the conceptual shift from point-like particles to 3-surfaces, offering a topological explanation for the family replication phenomenon[94] and relating Kähler magnetic monopole flux tubes to particle-like objects. This part emphasizes the role of partonic 2-surfaces and the homology of complex projective space in understanding particle dynamics.

94 Matti Pitkänen, Topological description of family replication and evidence for higher gauge boson generations, 9 August 2019 (tgdtheory.fi)

TGD – Space Hierarchy



This diagram illustrates the relationships and hierarchical organization of space structures in TGD. Causal Diamonds are integral parts of a larger, more encompassing system called the World of Classical Worlds. Spacetime surface X^4 is a subset of the imbedding Hyperspace H and a subset of Causal Diamond.

Appendix 4: Time-like Killing Vector Field

Noether's theorem implies that energy conservation and the conservation of momentum and angular momentum, typically reliable in uniform spacetime, face similar challenges in the more complex, curved spacetimes addressed by GR.

Preserving time translation symmetry in curved spacetime is a specific challenge tied to the existence of a particular type of vector field known as a Killing vector field ξ^{μ} or Killing field. This field represents time translation symmetry across the pseudo-Riemannian spacetime manifold.

A Killing field is defined by its ability to generate isometries of the spacetime metric tensor $g_{\mu\nu}$, meaning it preserves the distances between points when moving along the vector field's flow. Mathematically, this property is expressed by the condition that the Lie derivative of the metric tensor with respect to the Killing vector field vanishes to zero, i.e., $L_{\xi} g_{\mu\nu} = 0$.

A time-like Killing field is a special case where the vector field is time-like at every point. This implies that the dot product of the vector with itself yields a negative value when calculated with a Minkowski signature metric:

$$V \cdot V = g_{\mu\nu} V^{\mu} V^{\nu} < 0 \ .$$

Such a field indicates symmetry under time translations, implying that the laws of physics remain invariant over time. When a time-like Killing field exists, it endows a conserved quantity along geodesics, which can be interpreted as the energy of particles traversing these paths. However, this conservation does not occur if the time component of the metric tensor varies, i.e., in a dynamic spacetime.

To rephrase, the absence of a time-like Killing vector field, indicated by the dot product of vectors not being negatively signed when self-multiplied with the chosen metric, results in the loss of time translation symmetry. According to Noether's theorem, a spacetime with such a metric configuration does not support global energy conservation.

In GR, the utility of a rank-2 tensor object, such as the stress-energy-momentum tensor $T_{\mu\nu}$, is somewhat limited when handling globally invariant transformations.

This limitation arises because these tensor objects do not inherently account for symmetries of the spacetime manifold.

In a Killing vector field, the conserved quantities can be mathematically represented by an integral over a three-dimensional section of spacetime at a constant time value. In Einstein's field equations without cosmological term, expressed as $G_{\mu\nu} = kT_{\mu\nu}$ (where lower indices μ, ν = 1, 2, 3, 4), the tensor $T_{\mu\nu}$ encapsulates the distribution of matter and energy across spacetime.

When a tensor like $T_{\mu\nu}$ is contracted with a Killing vector, the result is a conserved current. This current corresponds to conserved quantities such as energy. Defining a simple scalar energy value as a three-dimensional integral over a spacetime slice without time-translation symmetry becomes impossible.

In flat Minkowski spacetime, everything works seamlessly. Noether called symmetries of M^4 proper conservation laws, referring to her first theorem. Another example is the Schwarzschild metric, which describes the gravitational field outside a spherically symmetric, non-rotating mass like a black hole or a non-rotating star. In such a spacetime, a time-like Killing field exists, and local and global energy conservation holds. Similarly, the Kerr metric, which describes a rotating black hole, only has a time-like Killing field in specific regions. This is true because the selected spacetime metric is symmetric by default, not that the theory gives the symmetries and yields only solutions obeying conservation laws.

However, in general, spacetimes that lack perfect symmetry in their matter and energy distribution will not possess a time-like Killing field. These are the countless realistic scenarios in the cosmos, where matter and energy distributions are neither uniform nor static.

For instance, a time-like Killing field is absent in cosmological models like the Friedmann-Lemaître-Robertson-Walker metric, which describes a homogeneous and isotropic expanding universe[95]. Situations characterized by outgoing or incoming gravitational waves or other radiation forms generally lack a time-like Killing field as the system's energy content evolves. Specific exact solutions to the Einstein field equations, like the Vaidya metric representing a radiating star, also lack time-like Killing fields.

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95 Cosmological models beyond the principle of homogeneity, such as LTB and the Bianchi models, are discussed in Peter Sundell's thesis Beyond the Cosmological Principle, Chapter 4, 2016 (utupub.fi).

Appendix 5: Pseudotensors

The pseudotensor t_σ^α that Einstein constructed and the energy vector e^l that Hilbert used independently of Einstein possessed a common property, which left conservation laws improper in a physical theory, as Noether expressed in her paper[96]. That is if GR was understood in a broader sense derivable from the variational principles, like the principle of least action and the framework of differential transformations associated with infinite-dimensional Lie groups[97].

What are the limitations of pseudotensors in GR? Pseudotensors provide only an approximate way to define the energy and momentum of the gravitational field, and this applicability is limited to certain specific situations. A significant drawback of pseudotensors is their lack of covariance: their transformation properties are consistent only under selected coordinates. This is inconsistent with GR, where covariance, or the principle of uniform transformation behavior under any coordinate change, is a fundamental requirement tracing back to the weak and strong equivalence principles.

Einstein was aware of the limitations of his pseudotensor, particularly its lack of symmetry, and he acknowledged the criticism this aspect drew. His defense was that, for instance, in classical mechanics, one often encounters equations like $\frac{\partial(T+U)}{\partial t} = 0$, where U is invariant under Galilean transformations, but T is not. This analogy indicates that the juxtaposition of general tensors T_σ^α with special quantities like t_σ^α in GR is not entirely unprecedented.

Einstein pointed out that in an accelerative field, t_σ^μ pseudotensor would exist even though the field could be transformed away. He emphasized that arbitrary concepts could be operationally useful in physics, even if they are not tensor quantities, drawing a parallel to using Christoffel symbols in GR, which are also not tensors. Moreover, unlike other classical forces, gravity in GR is exclusively attractive, not merely a feature within spacetime but constitutive of spacetime itself.

However, this defense by Einstein did not entirely convince physicists. Critics argued that a robust and elegant theory should avoid dependencies on constructs like

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96 Yvette Kosmann-Schwarzbach, (transl. Bertram E. Schwarzbach), The Noether Theorems - Invariance and Conservation Laws in the Twentieth Century (2011)

97 David Rowe, On Emmy Noether's Role in the Relativity Revolution (2018)

pseudotensors that can be perceived as tautologies, identities, or unphysical references. They contended that a sound theoretical framework, particularly one as foundational as GR, should be underpinned by principles and quantities that are universally valid and physically meaningful, free from ambiguities or inconsistencies.

The Landau-Lifshitz pseudotensor, introduced by Lev Landau and Evgeny Lifshitz in 1951, encounters similar limitations characteristic of pseudotensors in GR. Like Einstein's pseudotensor, it is coordinate-dependent, meaning its formulation and interpretation are tied to the specific choice of coordinate system. Additionally, it cannot be localized in the traditional sense familiar to Newtonian physics or SR. Instead, the Landau-Lifshitz pseudotensor allows for a so-called 'quasilocal' form of energy localization, a more nuanced and less straightforward concept than the classical notion of energy localization.

These limitations are not unique to the Landau-Lifshitz pseudotensor. Other pseudotensors developed in the context of GR, such as those proposed by Achilles Papapetrou, Christian Møller, and Steven Weinberg, share these limitations. While differing in their specific formulations and approaches, each of these pseudotensors grapples with the inherent challenge of defining a covariant, universally applicable, and physically meaningful representation of energy and momentum in the curved spacetime of GR.

Appendix 6: Theory of Everything

Introduction

Each discovery of distinct natural forces has led to ambitious unification attempts throughout history. From Newton's unification of terrestrial and celestial mechanics and Maxwell's unification of electricity and magnetism to Einstein's, Hilbert's, Kaluza-Klein's, Weyl's, and Nordström's attempts to unify gravity with electromagnetism, as well as Gustav Mie's work on mass-particles starting in the late 1910s[98], the pursuit of unification has been relentless. After the main tenets of quantum mechanics were established in the 1920s, the next step was the unification of quantum mechanics and electromagnetism, known as quantum electrodynamics, in the mid-20th century. In the 1970s, the triumph of the quantum field-based electroweak theory, which successfully merged electromagnetism and weak nuclear forces, inspired the search for a grand unification that combined the electroweak and strong nuclear forces.

A Theory of Everything (ToE) represents an extreme intellectual quest, building upon this lineage of unification. ToE embodies the ultimate aspiration in physics: to develop a single, coherent theoretical framework that explains and unifies all four of nature's fundamental interactions, not just the three, as in the still-hypothetical grand unified theories (GUTs). A successful ToE would enable us to comprehend the universe's workings at every scale of spacetime, from the tiniest particles to the vastest cosmic structures and everything in between. It endeavors to reconcile the macroscopic world described by general relativity with the microscopic world governed by quantum mechanics and the Standard Model of elementary particles.

Traditionally, ToE concept encompasses the synthesis of fundamental physics but may also extend to more complex phenomena, such as cosmology, biology, mathematics, philosophy, and even consciousness. In this appendix, we limit our investigation to introducing unification in physics and its close companion, cosmology.

[98] Classical unified field theories (wikipedia.org)

Brief History of Unification in Physics

The historical progression toward understanding the universe's forces is a testament to the pursuit of knowledge by some of history's most brilliant minds. The narrative begins with recognizing gravity, an omnipresent force of attraction. In 1687, Sir Isaac Newton provided a mathematical description of this force in his work "Principia Mathematica," establishing the laws of motion and universal gravitation, which stood as the cornerstone of classical mechanics. Of course, Newton did not invent or discover gravity, but he provided a theoretical framework to explain terrestrial and celestial phenomena under the same equations while setting a new method for modern science.

In the 18th century, Charles-Augustin de Coulomb formulated the law that describes the electric force. This law quantified the interaction between charged particles and laid the groundwork for understanding electrical phenomena. The magnetic force, long observed through phenomena like compass navigation, received a scientific basis through the works of William Gilbert in the 16th century and Hans Christian Ørsted and André-Marie Ampère in the 19th century. The culmination of these efforts was James Clerk Maxwell's synthesis of electricity and magnetism into a single theory in 1865, demonstrating that light is an electromagnetic wave. At that time, theories about atoms existed, but subatomic elements, like electrons, were experimentally confirmed only at the end of the 19th century[99]. The theory of light underwent its path of development from corpuscles to transverse waves and joined to a somewhat mysterious wave-particle duality at the beginning of the 20th century.

The weak nuclear force, responsible for processes such as radioactive decay, came into scientific purview through the late 19th and early 20th-century studies of radioactivity by pioneers like Henri Becquerel and Marie Curie. In the 1930s, Enrico Fermi proposed a comprehensive theoretical framework for this force. In the 1970s, the weak force was unified with electromagnetism into the electroweak force through the work of Sheldon Glashow, Abdus Salam, and Steven Weinberg. At that time, quantum mechanics and electromagnetism were already joined to quantum electrodynamics (QED) by Richard Feynman, Julian Schwinger, Sin-Itiro Tomonaga, and Freeman Dyson in the late 1940s and early 1950s. Paul Dirac laid the foundation for QED on spin-electron theory in the 1920s and 1930s.

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99 Atom - Dalton, Bohr, Rutherford (britannica.com)

The understanding of the strong nuclear force, which holds atomic nuclei together, was initially postulated by Yukawa Hideki in 1935[100]. The equation $E = mc^2$, derived from Albert Einstein's theory of special relativity in 1905, became particularly consequential for understanding and associated with the strong force. This equation elucidates the principle of mass-energy equivalence, which is important in understanding processes where a strong force is operative, such as nuclear fusion and fission, where massive amounts of energy are released from relatively small amounts of matter. A much more complete theory of the strong force evolved with the advent of quantum chromodynamics in the 1970s.

Einstein formulated the theory of general relativity in 1915/16, redefining the concept of gravity as a geometric property of spacetime rather than a force acting at a distance, as was posited in Newton's theory. Einstein's earlier work on special relativity had already revolutionized the understanding of space and time. Newton envisioned space and time as separate, static background properties in which rigid bodies moved[101]. Building on the mathematical insights of Hermann Minkowski[102], Einstein unified space and time into an interwoven fabric of spacetime in which curvature represents the presence of mass and energy. This was a remarkable demonstration of the equivalence of geometry and matter.

In this way, Einstein unified space, time, acceleration, gravity, mass, energy, and geometry, although he failed to achieve further unification, as did his contemporaries.

The concept of the luminiferous æther, long regarded as the medium for all natural phenomena, gradually faded into a historical curiosity and became a redundant principle with the advent of special relativity. Einstein's theory could explain relativistic effects without needing an æther, marking a significant shift in the conceptual framework of physics. This was supported by the famous null result of the Michelson-Morley experiment when they tried to prove æther experimentally[103].

In the latter half of the 20th century, the pursuit of GUTs emerged, driven by the ambition to unify the electroweak and strong forces. Figures such as Howard Georgi and Sheldon Glashow were central to these developments. Yet, despite

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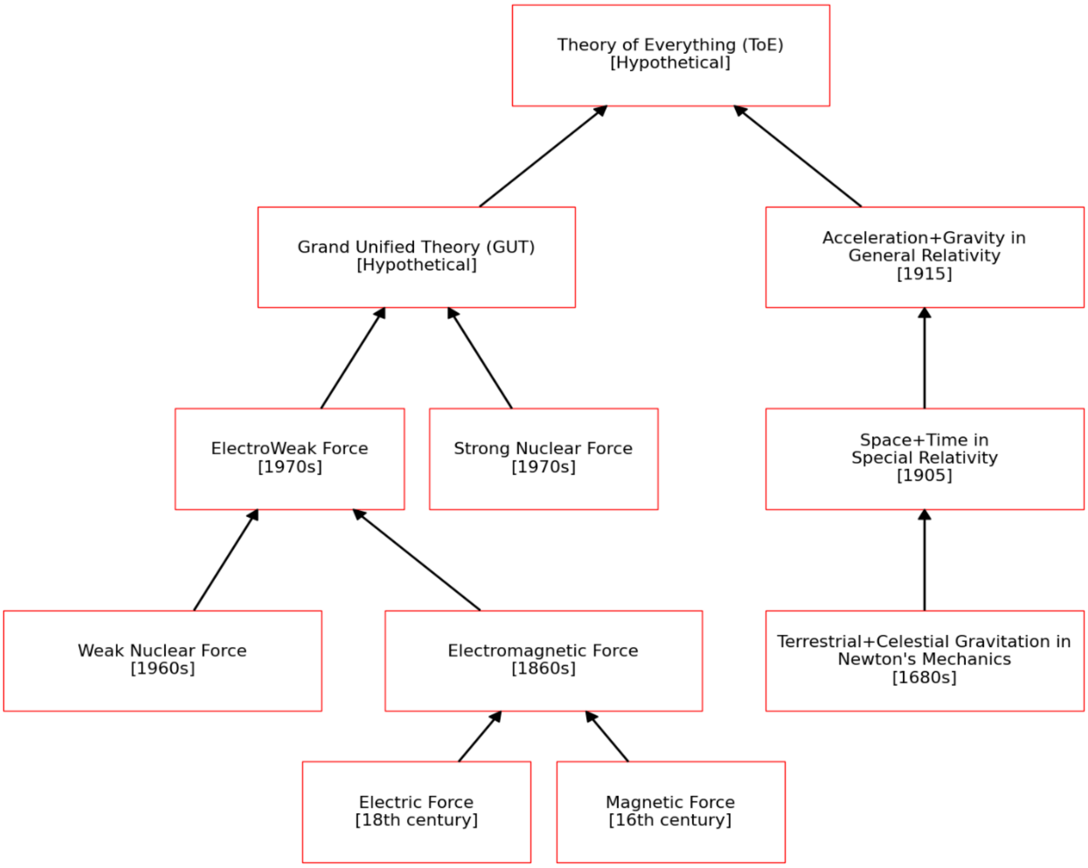
[100] Yukawa Hideki | Nobel Prize, Quantum Theory, Meson Theory (britannica.com)
[101] Newton's Views on Space, Time, and Motion (stanford.edu)
[102] GP-B - Einstein's Spacetime (stanford.edu)
[103] Michelson-Morley experiment | Description, Results, & Facts (britannica.com)

significant strides, this unification remains hypothetical and unfinished, much like ToE.

Due to a substantial body of evidence and research in the past century, the anti-ætheric principles of relativity, the constant speed of light, wave-particle duality, and nonlocality of quantum mechanics have been accepted by mainstream science. However, for dissident scientists and ToE enthusiasts, these ideas require constant review and contemplation, whether we have gotten everything right or missed something as these theories evolved and were accepted. From ToE perspective, something is missing or incomplete, but it is uncertain what that is.



Founding dates and relations of the fundamental force theories from the unification perspective[104]

[104] For a comparative sequence: Beyond the Standard Model (physics.info)

Quest for Unification

Unification of Fundamental Forces

The primary goal of ToE is the synthesis of the four fundamentals: gravitational interaction, electromagnetism, strong nuclear force, and weak nuclear force. This endeavor requires reconciling the large-scale phenomena described by general relativity with the quantum mechanical behavior of the subatomic world. The objective involves reevaluating their principles to establish a formal framework.

For instance, the quantization of gravity seeks to reconcile the probabilistic nature of quantum mechanics with the deterministic spacetime of general relativity. This endeavor confronts the task of resolving the inconsistencies between quantum field theory (QFT), which operates successfully for the other fundamental forces, and the classical framework of general relativity, particularly at the minuscule Planck scale of about 10^{-35} meters.

Although not ToE strictly speaking, loop quantum gravity (LQG) introduces a discretized spacetime, leading to mathematical structures such as spin networks. Yet, the challenge of creating a renormalizable theory remains. The non-renormalizable infinities encountered in the mathematically inconsistent path integral formulation further indicate the need for new physics or understanding at these extreme scales[105]. Also, graviton, the hypothetical carrier particle of gravitational interaction, has yet to be found. Discovering it would directly imply the quantization of gravity, a major challenge within current theories[106].

Simultaneously, the idea of a complete geometrization of quantum mechanics presents its difficulties. This approach aims to uncover symmetries between the forces and the structure of spacetime, indicating an underlying unity. It attempts to encapsulate the uncertainties and non-localities of quantum mechanics within a geometric framework akin to that of spacetime in general relativity. However, quantum mechanics inherently operates within a complex Hilbert space, where probabilities and quantum states are not easily translated into classical geometric language, albeit equivalent reformulation of quantum mechanics in classical phase

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[105] Assaf Shomer, A pedagogical explanation for the non-renormalizability of gravity, 15 December 2022 (arxiv.org)

[106] Germain Tobar, Sreenath Manikandan, Thomas Beitel, and Igor Pikovski, Detecting single gravitons with quantum sensing, 5 September 2023 (arxiv.org)

space is known[107]. Initiatives like Roger Penrose's twistor theory[108] attempt to redefine spacetime points with more complex structures to integrate quantum fields geometrically.

Emergent theories propose an even more radical paradigm, suggesting that both quantum mechanics and spacetime are manifestations of other, more foundational principles. The challenge lies in reconciling known physics and postulating and validating entirely new frameworks that could explain the known universe as a special case. String theory, a prominent example, posits one-dimensional strings and higher-dimensional branes as the elementary components, requiring extra spatial dimensions and leading to many possible universe solutions. The task then is not only to develop string models but to connect them to our observable reality and solve the so-called landscape and swampland problems—selecting the solution that corresponds to our universe from the myriad of possibilities[109].

The path chosen by ToE in addressing these three options will influence its theoretical structure, the implications it holds, and the empirical strategies required for its validation. Different theoretical physicists harbor various intuitions about which assumption would be the best. Typically, when a chosen approach solves one problem, it raises new ones. For instance, Peter Woit[110] and Eric Weinstein believes that after the 54-year struggle, starting from modeling the strong force, string theory has reached a dead end for that particular reason. It has raised more problems and failed predictions than it has solved and succeeded.

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[107] Anthony Bracken, Quantum Mechanics as an Approximation to Classical Mechanics in Hilbert Space, 1 February 2008 (arxiv.org)
[108] Twistor theory (wikipedia.org)
[109] Cosmic Predictions from the String Swampland, 28 October 2019 (physics.aps.org)
[110] Peter Woit, String theory is dead, 23 February 2023 (iai.tv)

Alignment with Established Theories (Where They Work)

A credible ToE must align with and encompass the well-established theories that describe how the universe operates at various scales and conditions.

Firstly, ToE must be consistent with general relativity at the classical limit when describing the macroscopic world of gravity and spacetime and with the Standard Model of particle physics at the QFT limit, which details the quantum world of particles and forces. It should replicate successful predictions and experimental confirmations under the conditions where they have been proven to work. This, however, does not mean that the theoretical foundations of ToE must be precisely the same as general relativity or gauge theories that underlie the Standard Model. For instance, Constructor Theory is a new approach to formulating fundamental laws in physics. Instead of describing the world in terms of trajectories, initial conditions, and dynamical laws, in constructor theory laws are about which physical transformations are possible and which are impossible, and why[111].

Secondly, ToE should provide a continuous understanding of physical phenomena, creating a bridge between the quantum origins of the cosmic structures observed today. It should present a coherent narrative connecting these seemingly disparate domains, especially in extreme conditions like black holes and the universe's beginning.

Optionally, ToE must address the issues of the arrow of time and entropy. It must elucidate the mechanisms behind time's directionality and the roles of entropy in the universe's evolution. This understanding is critical for explaining thermodynamic processes and the overall progression of cosmic events.

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[111] Constructor Theory (constructortheory.org)

Predictive Power and Empirical Foundations

Anomaly Explanation

The predictive power of ToE extends beyond merely reconciling existing knowledge; it offers forecasts of novel phenomena and explanations for observed anomalies beyond the scope of current models. The ability to predict previously unobserved phenomena is a critical test of the theory's validity and scientific worth. A new theory only holds value if it can offer something new to the scientific community and society.

ToE must provide precise and testable predictions regarding experimental and observational outcomes under unexplored conditions. This may encompass predictions about the behavior of matter at unprecedented energies or insights into spacetime dynamics at the Planck-length scale. Additionally, ToE should elucidate the mechanisms behind anomalies and discrepancies observed within the existing theoretical framework. Such anomalies include the properties of dark matter, the imbalance between matter and antimatter[112], and the intricacies of quantum entanglement and the quantum measurement problem[113].

Empirical Verification

Empirical verification is a cornerstone in validating ToE. The theory must propose concrete, testable predictions subject to empirical scrutiny.

Key components of this empirical verification include:

Testable Predictions: ToE should forecast specific unification signatures observable in cosmic microwave background anomalies or peculiarities in black hole thermodynamics. These predictions could pinpoint energy scales or conditions where new phenomena might emerge, guiding future high-energy physics experiments and astronomical observations.

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112 Elizabeth Gibney, Physicists see new difference between matter and antimatter, 21 March 2019 (nature.com)

113 Anil Anathaswamy, Quantum Theory's 'Measurement Problem' May Be a Poison Pill for Objective Reality, 22 May 2023 (scientificamerican.com)

Compatibility with Existing Data: The theory must not only replicate the success of general relativity and the Standard Model but also provide a basis for the values of physical constants and the symmetry properties of nature. It should explain phenomena like the quantization of charge[114] or the specific patterns in the particle mass spectrum[115] [116].

Novel Experimental Implications: ToE might predict entirely new states of matter, like exotic forms of quantum condensates, or suggest quantum gravitational effects observable under extreme conditions. It could also indicate subtle deviations in well-established phenomena, prompting re-examining of existing experimental data with finer precision instruments. For instance, the conundrum between the gravitational effects of the quantum entangled particles may resolve only with ultra-high precision measurements[117].

Falsifiability: ToE might specify particular energy levels where force unification should occur or describe distinct astrophysical signals incompatible with its framework. These benchmarks would provide clear, empirical lines in the sand, beyond which the theory would be considered invalid.

This is a challenging task because science is a constantly evolving field. When new experimental data emerges, they may challenge previous understandings. A theory that aligns with the data today might not fit tomorrow. Likewise, current data might contradict existing theories, but this may change with future discoveries. There is always some uncertainty in theories that attempt to model reality.

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[114] 6.2: Quantization: Planck, Einstein, Energy, and Photons (chem.libretexts.org)
[115] 3.2: The Quantization of Energy (chem.libretexts.org)
[116] 33.4 Particles, Patterns, and Conservation Laws - College Physics 2e (openstax.org)
[117] Gravitationally Induced Entanglement between Two Massive Particles is Sufficient Evidence of Quantum Effects in Gravity by C. Marletto and V. Vedral, 15 December 2017 (harvest.aps.org)

Particle Physics and Cosmological Perspectives

More Detailed Predictions in Particle Physics

ToE must deliver precise, comprehensive predictions in particle physics, enhancing our understanding of fundamental particles and their interactions. This endeavor requires addressing multiple aspects of the theoretical framework.

A few of them are the following:

Scattering Amplitudes and S-Matrix[118]: In the context of scattering amplitudes and the S-matrix, ToE should offer nuanced calculations. For instance, in QED, the scattering amplitude for electron-electron interactions, known as Møller scattering, is calculated using Feynman diagrams, and the results align exceptionally well with experimental data[119]. The S-matrix encompasses all possible transitions and is critical in processes like electron-positron annihilation. For this reaction, a specific S-matrix element determines the probability of an electron and positron annihilating to produce two photons. ToE should replicate these well-understood phenomena and possibly predict new, verifiable interactions extending beyond the scope of the scattering data.

Cross Sections and Decay Products: ToE should predict particle interactions at least with the same accuracy, particularly regarding cross sections and decay products. For example, it should precisely predict the cross section for Higgs boson production, which, in the case of a 125 GeV[120] Higgs at the Large Hadron Collider[121], was a critical prediction of the Standard Model. Similarly, understanding decay products, such as the various decay paths of the Z boson into quarks and leptons, is important. We are still struggling with why there are three generations of them[122]. ToE would refine these predictions and explain deviations or anomalies.

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[118] Ethan Siegel proposes a set of challenges to consider for a serious ToE in the interview with Timothy Nguyen, Mar 17, 2023 [4:14]: Testing Eric Weinstein's and Stephen Wolfram's Theories of Everything | Ethan Siegel & Tim Nguyen (youtube.com)

[119] Møller scattering (wikipedia.org)

[120] CMS Collaboration, Measurements of the Higgs boson production cross section and couplings in the W boson pair decay channel in proton-proton collisions at √ s = 13 TeV, 20 July 2023 (arxiv.org)

[121] CMS Collaboration, Evidence for the direct decay of the 125 GeV Higgs boson to fermions, 22 June 2014 (nature.com)

[122] Maarten Boonekamp and Matthias Schott, Electroweak Interactions and W, Z Boson Properties, 17 December 2020 (oxfordre.com)

Mass Spectrum and Branching Ratios: ToE should also offer insights into the observed particle mass spectrum. The masses of quarks, ranging from the up quark's 2.2 MeV/c^2 to the top quark's 173 GeV/c^2, are yet unexplained parameters within the Standard Model[123]. Additionally, ToE should accurately predict branching ratios, which is crucial for understanding particle decays. For instance, it should explain the precise branching ratio of B meson decays, like its decay to a K* meson and a photon[124]. These ratios provide stringent tests for the Standard Model and potential windows into new physics.

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ToE should transcend the Standard Model, uncovering new testable insights and predictions in various experimental contexts, including particle accelerators. While extraordinarily successful, the Standard Model relies on nineteen experimental values inserted as parameters[125], sometimes without deeper theoretical justification. ToE aims to significantly reduce the number of these ad hoc parameters, deriving them from the first principles instead, if possible.

Moreover, ToE should look at the lower energy regime experiments. These experiments might offer more practical means for testing certain theoretical predictions, providing insights into particle and force behaviors under more commonly accessible conditions[126]. This approach would serve as a complement to the high-energy experiments typically associated with particle physics.

More Comprehensive Cosmological Insights

ToE could extend its scope to the expansive canvas of cosmological phenomena, necessitating a detailed examination of the large-scale structure and dynamics.

Several areas require focus, like:

[123] The Standard Model (physics.info)
[124] Branching fraction (wikipedia.org)
[125] Standard Model Lagrangian (wikipedia.org)
[126] For instance, various authors, Testing the effects of gravity and motion on quantum entanglement in space-based experiments, 21 May 2014 (iop.org)

Mass Clustering and Cosmic Expansion: ToE should offer a comprehensive explanation for the observed distribution and clustering of mass, including galaxies, clusters, and superclusters. It should, for instance, explain phenomena like the Bullet Cluster, where visible matter is separated from the bulk of mass inferred to be dark matter[127]. The theory must also accurately account for the universe's expansion rate, as indicated by the Hubble constant, estimated at 70 km/s/Mpc.

Recent observations, like those from the James Webb Space Telescope (JWST) revealing rapid galaxy formations less than seven hundred million years after the Big Bang, present challenges to the Standard Model of cosmology[128]. ToE must reconcile these observations, integrating them with our understanding of cosmic inflation and the universe's projected evolution. Such a theory should not only elucidate the mechanics of mass clustering and expansion but also predict phenomena that could be observed with advancing technology.

Formation of Black Holes: ToE is expected to provide an understanding of black holes, detailing their formation from the gravitational collapse of massive stars and their evolution over time. This includes insights into stellar-mass black holes, typically 5-20 times the mass of the Sun, and supermassive black holes, which can be billions of times more massive, such as Sagittarius A* at the center of the Milky Way.

ToE should address the information paradox and the fate of information within black holes, integrating recent observations of black hole shadows and gravitational waves from black hole mergers. It should incorporate the physics behind event horizons and singularities, drawing from observations like the gravitational waves from merging stellar-mass black holes detected by LIGO[129] [130] or the shadow of the supermassive black hole M87* captured by the Event Horizon Telescope[131]. The theory should reconcile these phenomena with quantum mechanics, offering a coherent

[127] Bullet Cluster: Direct Proof of Dark Matter (chandra.harvard.edu)
[128] Michael Boylan-Kolchin, Stress testing ΛCDM with high-redshift galaxy candidates, 13 April 2023 (nature.com)
[129] Patricia Schmidt, Gravitational Waves From Binary Black Hole Mergers: Modeling and Observations, 16 June 2020 (frontiersin.org)
[130] Fupeng Zhang, Lijing Shao, and Weishan Zhu, Gravitational-wave Merging Events from the Dynamics of Stellar-mass Binary Black Holes around the Massive Black Hole in a Galactic Nucleus, 29 May 2019 (iop.org)
[131] Press Release: Astronomers Capture First Image of a Black Hole, 10 April 2019 (eventhorizontelescope.org)

description of black hole interiors and the potential for new holographic physics at these gravitational limits[132].

Dark Matter and Dark Energy: A critical challenge for ToE is to elucidate the nature of dark matter, which constitutes about 27% of the universe's mass-energy composition. Observations such as the rotation curves of galaxies, which show outer stars orbiting faster than expected, suggest the presence of unseen mass[133].

Additionally, ToE should provide an understanding of the cosmological constant, which contributes to dark energy, accounting for approximately 68% of the universe's mass-energy. This force drives the universe's accelerated expansion, as evidenced by observations of distant Type Ia supernovae[134]. A comprehensive ToE would integrate these phenomena, offering new perspectives on space, time, and gravity. ToE could also challenge the current ideas about dark energy and matter, inflation, charge conjugation parity (CP) symmetry violation (matter-antimatter imbalance), and the Big Bang.

Formation of Celestial Bodies: ToE should also offer a detailed framework for the formation and evolution of various celestial bodies, including stars, planets, and exotic structures like neutron stars and pulsars. It must accurately describe processes such as stellar nucleosynthesis, which explains the formation of elements within stars[135]. The theory should incorporate planetary formation theories, drawing from observations of protoplanetary disks and star-forming regions like the Orion Nebula.

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ToE, to be recognized as a successful and comprehensive framework, must weave together an understanding of phenomena across both quantum and cosmic scales, tackling the complexities and anomalies that recent observations, such as those from the JWST, have unveiled. These observations, which challenge current cosmological models like ΛCDM—Lambda stands for a cosmological constant and CDM for Cold Dark Matter—include the early formation of massive galaxies and the unexpected behaviors of cosmic structures.

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132 Paul Sutter, The holographic secret of black holes, 19 December 2023 (phys.org)
133 Galaxy rotation curve (wikipedia.org)
134 The 2011 Nobel Prize in Physics - Press release, 4 October 2011 (nobelprize.org)
135 Stellar nucleosynthesis (wikipedia.org)

Had ToE been able to predict these 2023 observations, it would have been a strong vindication of its accuracy and validity. Consequently, the theory must adapt to these new findings, providing explanations that align with the observed data and maintain a cohesive narrative from the universe's beginning. While integrating post-predictions is valuable, the ability of a theory to make preemptive, accurate predictions is a more impressive measure of its validity and effectiveness.

Aesthetic and Theoretical Considerations

Principle of Parsimony

In the formulation of ToE, the principle of parsimony, commonly known as Occam's Razor, along with aesthetic considerations, influences theoretical development and evaluation. It is possible to develop physical intuition suitable for unification only by long studies and slow progress. While not empirical in the traditional sense, these principles provide philosophical and heuristic guidance.

Principle of Parsimony: ToE should embody the principle of parsimony, suggesting that the one with the fewest assumptions should be preferred among competing hypotheses. This principle does not equate simplicity with correctness but implies that a less assumptive, yet adequate explanation is preferable. ToE should pursue elegance and simplicity in its foundational principles rather than at the cost of comprehensive accuracy.

Balanced Simplicity: Simplicity is indeed a virtue, yet ToE must not diminish the inherent complexity of the universe. The theory should be as streamlined as necessary to describe known phenomena coherently.

Aesthetic Considerations: Scientists often regard aesthetic qualities such as elegance, beauty, and symmetry as indicators of truths. Although subjective and not empirically verifiable in the traditional sense, these qualities frequently influence theoretical development. ToE characterized by mathematical beauty or symmetry may be more inclined to mirror the inherent order of the universe. Beauty and elegance are the words to describe an equation or theory that unexpectedly captures reality, sometimes yielding much more than the theorists themselves could have anticipated.

Heuristic Role of Aesthetics: Aesthetics frequently serve a heuristic function in theory development, steering scientists toward solutions that intuitively 'feel' correct based on the specialization of the subject matter. While these considerations are not replacements for empirical validation and logical coherence, they are valuable in motivating and guiding the exploration and refinement of ToE.

Truth as the Ultimate Goal: The paramount objective of ToE is to reveal the universe's truths. While simplicity and aesthetic appeal may facilitate this quest, they are subordinate to the theory's empirical accuracy and truthfulness.

By integrating the principles of parsimony and aesthetics, ToE should strive for a formulation that minimizes unwarranted assumptions while resonating with simplicity and beauty. Many Nobel laureates (Einstein, Chandrasekhar, Penrose, Wilczek) have confessed to being guided by intuition and beauty principles, but it can also lead thoughts to the wrong paths, which is why self-criticism and iterative validation are always required.

Mathematical and Methodological Rigor

Mathematical Consistency: A robust ToE mandates mathematical consistency, achieved through tools like advanced computational models and theoretical frameworks. It requires resolving physical singularities and anomalies, employing non-standard geometries or quantum gravity theories. Predictive precision necessitates tools like numerical simulations and symbolic computation for accurate predictions and empirical testing. Mathematics should maintain internal coherence, align with symmetries and conservation laws, and illustrate established theories as subsets of a broader system, utilizing tools like group theory, topology, differential geometry, and tensor analysis.

Methodological Rigor: This demands a disciplined approach using analytical tools like logical positivism and empirical scrutiny alongside synthetic methods that integrate disparate phenomena through complex systems theory and interdisciplinary research. Rigorous analysis involves tools like peer review, statistical validation, and falsification tests. The synthetic approach requires comprehensive data analysis and modeling software to unify diverse physical phenomena. Collaborative platforms and peer networks facilitate critical examination, while adaptability hinges on continuous data assimilation and theoretical updates.

These tools ensure ToE is a dynamic, scientifically robust framework rather than a static, barely speculative concept.

Enhancing Understanding and Accessibility

Self-Explanation and Educational Accessibility

ToE should be crafted to promote understanding and educational accessibility at all levels. These aspects affect the theory's acceptance, widespread dissemination, and continual evolution within the scientific community and the wider public.

Intrinsic Self-Explanation: ToE should be self-explanatory, incorporating clear principles and mechanisms within its structure that render its concepts and predictions comprehensible. This requires presenting the interrelations of the universe's various components and forces logically and intuitively based on the theoretical framework.

Educational Accessibility: The theory needs to be approachable for learners of different levels. Although some implications and details of ToE might be accessible only to specialists, efforts should be made to articulate its principles and implications in ways non-experts can also understand. This should include the development of educational resources that convey the theory in clear and relatable terms.

Comprehensive Resources: For individuals seeking an in-depth understanding, ToE should be supported by a wide array of detailed resources, including peer-reviewed papers, textbooks, and other educational materials. These resources should methodically outline the theory's formulation, providing a systematic and thorough presentation of the theory and its aspects.

Reference Framework: ToE should function as a reference point for further study and investigation. It should delineate the scope of knowledge it covers and provide references to the foundational work and empirical data it is based on. This framework should assist learners and researchers in navigating the landscape of theoretical physics and related fields.

Facilitation of Deep Understanding: Educational materials and resources associated with ToE should inform and facilitate comprehension of the theory and its implications. This involves fostering an environment that encourages critical thinking, exploration, and the development of a nuanced perspective on the theory's strengths, potential limitations, and areas open to further inquiry.

The intrinsic explanatory power and educational accessibility of ToE are important to its sustained relevance and impact. By ensuring the theory is as comprehensible and accessible as possible, its architects and advocates can cultivate broader and deeper engagement, inspiring a new generation to examine, question, and build upon its principles.

Comparative Analysis with Dissident Theories of Everything

A comprehensive ToE requires a detailed comparative analysis with leading ToE proposals. This examination highlights the new theory's unique contributions, strengths, and potential limitations within existing frameworks. Prominent theories often included in this rather wild field are string models like Superstrings and M-Theory[136], LQG[137], and other emerging approaches like E8 − the exceptional Lie group[138], Wolfram Physics[139], Geometric Unity[140], and Topological Geometrodynamic[141] (TGD).

The comparison of theoretical foundations involves examining the new ToE's assumptions and structures. String models posit particles as one-dimensional strings vibrating in higher-dimensional space. LQG suggests spacetime is quantized into discrete loops or spin networks. E8 Theory views particles as excitations of the largest exceptional Lie group. Wolfram's hypergraph approach models spacetime as computational networks. Geometric Unity aims to unify physics through geometric structures, pairs of spaces, and equations in the square root relation yielding the

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136 M-theory (wikipedia.org)
137 Introduction to Loop Quantum Gravity - Rovelli's lectures on LQG, 20 May 2023, transcribed by Pietropaolo Frisoni (arxiv.org)
138 Garrett Lisi and James Weatherall, A Geometric Theory of Everything, December 2010 (cs.virginia.edu)
139 The Wolfram Physics Project (wolframphysics.org)
140 Geometric Unity (geometricunity.org)
141 Matti Pitkänen, Introduction to "Topological Geometrodynamics: an Overview", 11 February 2020 (tgdtheory.fi)

Einstein, Dirac, and Yang-Mills with Higgs field equations[142]. TGD theorizes a twistorized spacetime 4-surface embedded into an eight-dimensional hyperspace defined by a Cartesian product of Minkowski and complex projective spaces, integrating gravity and quantum mechanics.

The new ToE can be effectively positioned within the scientific arena by conducting a thorough comparative analysis. Usually, this is done by popularizers of science. But, if left to third parties alone, there is a danger of falling to naive extrapolations of the details of the theories.

Broader Interdisciplinary Approaches

Approaches to the Theory of Everything

Broadening the scope of ToE to incorporate disciplines such as biology, technology, philosophy, and ethics demands an interdisciplinary approach. Each field introduces its challenges.

Biology and ToE: Merging biological principles with ToE entails exploring how life manifests from the laws of physics and chemistry. It necessitates considering evolution, complexity, and the origins of life. Delving into the organization and behavior of biological systems might yield insights into the universe's underlying principles.

Technology and Predictive Frameworks: Technology and information theory can provide distinct perspectives on ToE. This includes examining how principles of computation, information processing, and technological progression are intertwined with the laws of physics. An understanding of these principles could assist in predicting technological evolution and its implications for society.

Philosophical Foundations: Philosophy offers insights into reality, existence, and knowledge. Engaging with philosophical inquiries and incorporating metaphysical, epistemological, and ontological insights can enrich the theory. This involves

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[142] Into the Impossible, Dr Brian Keating Podcast, Dec 31, 2020 [22:55]: Max Tegmark & Eric Weinstein: AI, Aliens, Theories of Everything, & New Year’s Resolutions! (youtube.com)

dissecting the nature of causality, the fabric of reality, and the boundaries of human comprehension.

Ethical and Social Implications: A comprehensive ToE should also reflect on its findings' ethical and societal repercussions. This includes pondering how comprehension of the universe might influence our perspectives on ethics, purpose, and our place within the cosmic order. It also necessitates considering the potential societal ramifications of technological advancements that ToE might predict or facilitate.

Conscious Experience and ToE

In the quest to develop a comprehensive ToE, including and understanding consciousness is a profound challenge. Theories addressing consciousness within the context of ToE explore various philosophical stances, each offering a distinct perspective on the relationship between consciousness and the physical world. These perspectives challenge traditional materialistic paradigms and provide a richer understanding of the subjective and experiential dimensions.

Idealism: This philosophical viewpoint posits that consciousness or mind is the essence of reality. In this framework, physical phenomena are considered manifestations or constructs of the conscious mind. ToE based on idealism would suggest that understanding consciousness is vital to comprehending nature, with the physical laws being derivative of or emergent from consciousness itself.

Dualism: Dualism is the belief in the dual nature of reality, positing that consciousness (or mind) and the physical world are two distinct, irreducible substances or realms. In the context of ToE, dualism implies that any comprehensive theory must account for the physical universe and the realm of consciousness as separate but interacting entities. This approach faces the challenge of explaining the interaction between mind and matter.

Panpsychism: Panpsychism suggests that consciousness or a mind-like aspect is a fundamental and ubiquitous component of the physical world. It posits that everything, from the smallest particle to the largest galaxy, possesses some form of consciousness or experiential quality. To embrace panpsychism would seek to understand how consciousness permeates the fabric of reality and how consciousness, such as human experience, emerges from simpler forms.

Non-Reductive Physicalism: This perspective acknowledges that while consciousness arises from physical processes, it cannot be entirely reduced to these processes. In a non-reductive physicalist ToE, consciousness is considered an emergent property of certain complex systems, like the human brain.

Incorporating consciousness into ToE requires an approach that embraces insights from neuroscience, psychology, philosophy, and even spirituality. It necessitates considering how subjective experience arises from and interacts with the objective world. This integration poses additional challenges that are already enormous without incorporating the mind-and-matter unification program, but it also offers the potential for a more holistic understanding of reality.

Conclusion

Recap of the Key Points

This appendix has embarked on a journey through ToE scene, deliberately maintaining transparency to any particular formulation. It addressed the all-around nature of ToE, from the unification of fundamental forces to the speculative integration of consciousness, emphasizing the necessity for mathematical consistency, methodological rigor, and interdisciplinary integration.

While outlining specifications at this level is straightforward conceptually, their actual implementation within a theoretical framework presents huge challenges. Many existing ToE proposals offer key ideas, sometimes in mathematical formalism, yet often lack a comprehensive framework that explicitly explains foundational questions and fits into a grand scheme.

The appendix highlighted essential components and challenges in formulating ToE that are scientifically robust, philosophically profound, and universally accessible, acknowledging the hurdles inherent in this quest.

A successful ToE would represent a monumental scientific achievement elucidating questions about the universe's origin and fate. It would culminate centuries of scientific inquiry.

Critical View on Unification Attempts

While pursuing ToE is a noble and ambitious goal, it is fraught with challenges and controversies. Many argue that it is impossible to achieve within a single generation, let alone by individual efforts. Unification attempts must navigate the complexities of merging disparate theories, the speculative nature of advanced physics, and the profound philosophical implications. It may require the discovery of new branches of mathematics, potentially too complicated for most to understand. Additionally, a single unified theory or “god” equation might be unattainable or nonexistent. We should remember that Hilbert’s unification program for mathematics failed due to Gödel’s incompleteness theorems. Nature might be dualistic, allowing only partial unification under the same mathematical formalism. Or we may discover a fifth force, rendering the unification of the four fundamental forces incomplete. The quest for ToE might inadvertently overlook other valuable scientific inquiries and risk individual academic careers if not balanced with different research topics.

Despite these challenges, the pursuit of ToE inspires many theoreticians and seekers, embodying humanity's enduring desire to uncover the truth. In the history of unifications, each leap forward has reshaped our understanding of nature, led to technological advancements, enhanced our predictive capabilities, and altered our mental place in the cosmos. Even if we find ourselves on an ever-ending quest with ToE, curiosity may turn out rocks that reveal something unexpected that advances science and life in general.

Appendix 7: Topological Geometrodynamics - Theory of Everything and More

Topological Geometrodynamics (TGD) is a less-referenced Theory of Everything (ToE) in public discussion. Yet, it offers a unique approach to unifying all four fundamental forces and particles, aligning with the traditional objectives of ToEs in theoretical physics. TGD integrates gravity with the Standard Model using a classical quantum mechanical framework with a geometric approach.

Exceptionally, while this theory began with topological geometrization of physics, it also explores a number-theoretical side, incorporating p-adic numbers and Adelic physics as a dual to the theory. Furthermore, Adelic physics forms the foundation of the TGD-inspired theory of consciousness. In that sense, TGD is more than physics ToE.

TGD presents a complex framework with a steep learning curve. Understanding its core concepts, especially the derivation of the geometric side of the framework, is crucial for fully appreciating its approach to unification. The following is a concise overview of the geometric side of TGD theory.

Geometric Framework

TGD approaches ToE unification by geometrization and topological treatment, in some sense continuing the work of an American theoretical physicist, John Archibald Wheeler. The two central tenets in TGD geometry are:

- The selection of the imbedding hyperspace, where all interesting geometric structures and symmetries reside.
- The induction of the basic structures of the hyperspace to tangent space along the spacetime 4-surface, which can be Euclidean (related to the geometry of flat spaces) or Minkowskian (related to spacetime in relativity) in signature.

For various reasons, hyperspace in TGD is selected as a Cartesian product of the Minkowski space and two-dimensional complex projective space, mathematically denoted by $H = M^4 \times CP_2$. Shortly, it enables symmetries required for both relativity and the Standard Model gauge fields. Via the induction process, various vector fields related to the geometry of the hyperspace at the points of the 4-surface are projected to the tangent space of the 4-surface. The same applies to the metric tensors of the hyperspace. This procedure is known as induction in the theory of vector bundles.

In TGD, spacetime is a familiar 4-D space. The symmetries come from the static 8-D imbedding hyperspace, which acts as isometries on the spacetime surface similar to rotations and translations acting on rigid bodies. The spacetime surface in TGD becomes dynamic and adheres to specific extremal conditions under the application of the variational principle. The varied action is a sum of Kähler action and volume term from twistorization replacing Minkowski space and complex projective space by their twistor spaces and spacetime surface with its twistor space.

Twistorization of the hyperspace gives the theory a cosmological constant as an interpretation of the volume term and all elegance of twistors in place of spinors. The twistor lift is remarkable for the selected hyperspace since twistor spaces have a Kähler structure only in this configuration. Additionally, the two-dimensional complex projective space is characterized by a $spin^c$ structure and $SU(3)$ symmetry, which explains how quarks are bound inside protons, neutrons, and other hadrons.

In TGD, the Standard Model quantum numbers and fundamental particles are classified by topological invariants assigned to wormhole contacts in many-sheeted spacetime. In the QFT limit, electromagnetic, gravitational, and Yang-Mills field equations emerge, aiming to unify fundamental physics theories and resolve the quantum measurement problem in TGD.

The induction approach distinguishes TGD from string models, which typically extend spacetime from Minkowski space to higher dimensions and focus on vibrating strings rather than surfaces. Consequently, compactification, the process of reducing higher-dimensional spaces to the familiar four dimensions of spacetime, is not needed in TGD. Unlike traditional grand unified theories or many ToEs, TGD does not approach partial or complete unification through super-groups, which approach has become obsolete because of the potentially infinite number of groups from which to choose. This is analogous to the landscape problem in string models, where an unimaginable number of compactification versions exist. TGD also avoids path integral and the process of renormalization, one of the perplexing mathematical tools required in currently prominent QFT formalism. Field quantization is irrelevant in TGD as well.

Other key concepts in TGD are Zero Energy Ontology, the World of Classical Worlds, magnetic bodies and flux tubes, causal diamonds, an infinite hierarchy of phases of ordinary matter labeled by effective Planck constant and identified as dark matter, small and big state function reductions, time reversal, negentropy, among others. The complexified octonionic structure in number theory, a relatively new and unexplored territory in theoretical physics, is dual to geometric physics in TGD.

TGD theory is effectively fractal and holographic, referring to whole-in-part structures and offering exciting predictions across all scales of natural phenomena, including condensed matter, high-energy and low-energy physics, cosmology, and biology.

There is only one coupling constant in TGD whose spectrum is determined by quantum criticality. One goal of an ideal ToE would be to explain the constants of nature with as few ad hoc values as possible.

From these objectives, one can already see that TGD is a radically different framework from a mainstream theoretical physics standpoint. Extensive work has been done to support the theory by examining the latest experimental findings. In particular, those findings with unexplained anomalies in physics, cosmology, and biology have been examined through the lens of TGD.

Scientific Inquiry

The problem of general relativity related to energy and momentum conservation laws was the starting point of the theory when a Finnish theoretical physicist, Dr. Matti Pitkänen, developed TGD in the late 1970s and wrote his Ph.D. thesis in 1982.

The international academic study program largely neglected theories beyond string models, making TGD theory a solo endeavor in theoretical physics. Leaving Helsinki University in the 1990s had repercussions. Although it led to limited public support, it also enabled the development of the theory with complete freedom and independence.

For over forty years, Dr. Pitkänen has shared his contributions through peer-reviewed journal articles, ResearchGate papers, and extensive blog posts, collectively spanning thousands of pages and over twenty books. The latest comprehensive edition of the Topological Geometrodynamics book was published by Bentham Books in 2016, and ongoing explorations in TGD can be found on the homepage of tgdtheory.fi and the TGD diary blog matpitka.blogspot.com.

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