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Theory of everything: a review

Abstract

Imagine a vast and complex puzzle, with countless pieces scattered throughout the universe. Each piece represents a fundamental aspect of our reality - from the tiniest subatomic particles to the largest cosmic structures. For centuries, scientists have been striving to assemble this puzzle, seeking to uncover the underlying principles that govern the behavior of the universe as a whole. Enter the Theory of Everything (ToE) - a concept that promises to provide the ultimate answer to this puzzle. This theory seeks to unite the fundamental forces of nature into a single, elegant framework, revealing the underlying unity and interconnectedness of the universe. It represents the pinnacle of scientific achievement - a unifying theory that could transform our understanding of the cosmos and unlock the mysteries of existence itself. In this paper, we discuss some of the most fundamental features of such theory in both physical and philosophical aspects.

Keywords: Theory of Everything (ToE), Theory of Almost Everything (ToAE), Grand Unified Theories (GUTs), (Beyond) Standard Model, String theory, M-theory, General Relativity, Quantum Mechanics

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Introduction

The quest for a Theory of Everything (ToE) has a rich history spanning centuries, and it has been a driving force behind many of the greatest scientific breakthroughs in history. It began with the ancient Greeks, who sought to understand the nature of matter and the universe, and continued through the Renaissance, when scientists like Galileo and Newton laid the foundation for modern physics. In the 19th century, James Clerk Maxwell developed a set of equations that described the behavior of electromagnetic waves, unifying the fields of electricity and magnetism into a single framework. This was a key step in the development of a unified theory, as it demonstrated that seemingly separate phenomena could be explained by a single set of laws. In the early 20th century, physicists discovered that there were four fundamental forces at play in the universe - electromagnetism, the strong nuclear force, the weak nuclear force, and gravity. Each of these forces operates on a different scale, and physicists have been working to unify them into a single, elegant framework—a ToE.

One of the first attempts to unify the forces was made by Albert Einstein, who developed the theory of general relativity, which described gravity as a curvature of spacetime. While this was a major breakthrough, it did not incorporate the other three forces, and efforts to unify them continued. During that epoch, gravity and electromagnetism were the exclusive fundamental forces that had been ascertained. It was during this juncture that a remarkable concept emerged namely, the Kaluza-Klein theory. This theory is a theoretical framework that seeks to unify gravity and electromagnetism by introducing extra spatial dimensions beyond the familiar four dimensions of space and time. The theory was first proposed in 1921 by Theodor Kaluza, a German mathematician and physicist, and later extended by Oskar Klein, a Swedish physicist. The central idea of the theory is that the universe has more dimensions than we can perceive, and that these extra dimensions are compactified, meaning they are curled up and hidden from our everyday experience. In this theory, particles and fields can be described not only in terms of their familiar four-dimensional properties, but also in terms of their properties in the extra dimensions.

In the 1950s and 1960s, the theory of quantum mechanics was developed, which described the behavior of subatomic particles. This led to the development of the standard model of particle physics, which unified the electromagnetic and weak nuclear forces into a single framework known as electroweak theory.[1] However, the strong nuclear force, which holds atomic nuclei together, remained separate. This led to the development of the theory of quantum chromodynamics, which describes the behavior of quarks and gluons, the particles that make up atomic nuclei. Despite these developments, attempts to unify the four fundamental forces into a single ToE remained elusive. Many proposed theories of everything, such as string theory, which suggests that particles are made up of tiny, vibrating strings of energy, remain unproven and controversial.

In recent years, advances in technology and the development of massive experiments, such as the Large Hadron Collider, have provided new insights into the behavior of particles and gravitational waves, and the search for a ToE continues. In light of the theory's esteemed reputation, it is reasonable to pose the question as can there really be a unified ToE; or are we just chasing a mirage? As Hawking stated, there seem to be three possibilities:

a) There really is a complete unified theory, which we will someday discover if we are smart enough.

b) There is no ultimate theory of the universe, just an infinite sequence of theories that describe the universe more and more accurately.

c) There is no theory of the universe. Events cannot be predicted beyond a certain extent but occur in a random and arbitrary manner.

The present paper aims to examine the prevailing opinions regarding each of the aforementioned scenarios as addressed above.

This paper is organized as follows. In Sec. 2, the general concept of any theory that has the potential to be a candidate for the ToE will be presented, incorporating all pertinent details. The discerning criterion for a viable ToE will be identified as its conformity with the fine-tuned constants. The references of this section are,[1-9] and.[10] Sec. 3 concerns the Theory of Almost Everything (ToAE), a theoretical construct that centers on the quantum realm while disregarding the force of gravity. Contemporary endeavors are predominantly directed

[1] However, as will be proved, electroweak theory, unlike Kaluza-Klein theory, is not a true unification.

towards the possibility of viewing gravity as an effective field rather than a fundamental one, as noted in reference to a prior work.[11] References that will be used in this section are,[1,2,4,7,9,12,13] and.[10] In Sec. 4, the focus shifts towards string theory, which is considered to be the sole credible contender for the all-encompassing theory, and we shall carry out a comprehensive evaluation of its dimensions in a critical manner.[10,13-17] At last, Sec. 5 will explore diverse philosophical and non-physical angles of the ToE with the references.[18-20]

General concept

The nature of fundamental laws has undergone changes with the discovery of new realms of phenomena and advancements in precision of scientific observation. However, the fundamental laws have been proposed to consist of two key components. The first component pertains to the dynamical laws which govern the regularities observed over time. For instance, Newton's laws of motion regulating the trajectory of, roughly speaking, celestial or any macroscopic bodies, the law of universal gravitation that asserts uniform acceleration of distinct entities in a gravitational field, and the Einstein equation which governs the evolution of the universe are illustrative examples. The second component is the initial conditions which govern the way in which things were set in motion and consequently provide for regularities in space. An instance of this could be the statistical regularities observed in the distribution of galaxies on a large scale within the universe. The fundamental principles of physics that make up a ToE are those that precisely determine theses regularities displayed by all physical systems, devoid of any exceptions, conditions, or approximations. The attainment of a ToE necessitates the consideration of fine-tuning constants. To be deemed an all-encompassing theory, it must unify not only all physical forces but also the fine-tuning constants that signify the alignment between dynamical laws and the universe. In the ToE, these constants must be derived from a hyper-fine-tuned constant.

Two examples

In this section, we aim to enhance comprehension of the fine-tuned hyperconstant by providing two examples.

Case I: In 1921, Theodore Kaluza and later Oscar Klein conducted research on general relativity that diverged from prevailing scientific thought. They proposed a compelling and seemingly uncomplicated approach that combined the two known forces of the time - electromagnetic and gravitational - by examining spacetime in five dimensions, then compressing one spatial dimension to reach the observable world. By analyzing the 5-dimensional metric structure, denoted as G_D, they found that it could be simplified into a 4-dimensional matrix, G_d along with a column matrix, A_μ a row matrix, $A^T{}_\mu$ and a positive-definite scalar, e^σ.

$$\begin{bmatrix} \text{Metric in the lower dimension} & \\ 4\times 4 & \text{Column Matrix} \\ & \\ \text{Row Matrix} & \text{Scalar} \end{bmatrix}_{5\times 5} \quad (1)$$

This implies that

$$ds^2 = G_{\mu\nu}dx^\mu dx^\nu + G_{44}\left(dx^4 + A_\mu dx^\mu\right)^2. \quad (2)$$

in which we have used $\mu\nu \in \{0,1,2,3\}$. With the standard general relativity calculation, we derive

$$R_D = R_d - 2e^{-\sigma}\nabla^2 e^\sigma - \frac{1}{4}e^{2\sigma}F_{\mu\nu}F^{\mu\nu} \quad (3)$$

as scalar curvature where $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ is the field strength tensor and ∇ is the covariant derivative. Plug this into the Einstein-Hilbert action one reads[2]

$$S = \frac{1}{2K^2}\int d^D x\sqrt{-G_D}e^{-2\phi}\left(R_D + 4\nabla_\mu\phi\nabla^\mu\phi\right) \quad (4)$$

$$= \frac{1}{2K^2}\int_0^{2\pi R}dx^4\int d^d x\sqrt{-G_D}e^{-2\phi+\sigma}\left(R_d - 4\partial_\mu\phi\partial^\mu\sigma + 4\partial_\mu\phi\partial^\mu\phi - \frac{1}{4}e^{2\sigma}F_{\mu\nu}F^{\mu\nu}\right) \quad (5)$$

where K is the Newton gravitational coupling constant in higher-dimensional theory. The first integral in Eq. (5) represents the compactification definition. By some straightforward algebra, one finds

$$S = \frac{\pi R}{K^2}\int d^d x\sqrt{-G_D}e^{-2\phi_d}\left(R_d - \partial_\mu\sigma\partial^\mu\sigma + 4\partial_\mu\phi\partial^\mu\phi - \frac{1}{4}e^{2\sigma}F_{\mu\nu}F^{\mu\nu}\right). \quad (6)$$

The usual The Yang-Mills action, which, roughly speaking, describes the quantum field theory of gauge interactions, including the strong and weak interactions, but not purely electromagnetism, is

$$S = -\frac{1}{4G_{\text{YM}}^2}\int d^D x\sqrt{-G_D}F_{\mu\nu}F^{\mu\nu} \quad (7)$$

where G_{YM} is the Yang-Mills gauge coupling constant. By comparing the result of Eq. (6) and Eq. (7), we achieve

$$G_{\text{YM}} = \frac{K}{\sqrt{\pi R}}e^{-\sigma}e^{\phi_d} \quad (8)$$

This elucidates the unification of electromagnetism and gravity in an exceedingly explicit manner. Within the Kaluza-Klein theory, gravity and electromagnetism are expounded within a unified 5-dimensional framework, and the respective constants corresponding to these theories are interrelated without any intervening factors. Precisely, gravity and electromagnetism can be unified in five dimensional framework.

Case II: In the process of unifying the electromagnetic and weak interactions, one must modify the current-current form of the weak interactions. Hence, one must assume that the current-current structure is an effective interaction which results from the exchange of massive vector bosons with only a small momentum transfer. For the sake of simplicity, the computation is ignored.[3] Ultimately, the so-called "electroweak unification" arises from the established definition of the weak hypercharge Y, given by $Q = T^3 + \frac{Y}{2}$ where Q generates the group $U(1)_{em}$ and T^3 its weak isospin. Expressed within the formalism

[2] In this work, we adopt the string frame, in which the metric $G_{\mu\nu}$ is directly related to the string theory action. In this frame, the gravitational sector includes a dilaton-dependent prefactor $e^{-2\phi}R$, meaning that the strength of gravity varies with the dilaton field ϕ. This contrasts with the Einstein frame, where a conformal transformation $g_{\mu\nu} = e^{-2\phi/(D-2)}G_{\mu\nu}$ is applied to bring the gravitational action into the standard Einstein-Hilbert form. While the Einstein frame is more suitable for direct comparison with general relativity, the string frame is more natural in higher-dimensional theories, as it preserves the original coupling structure of the theory. Since our analysis is focused on the fundamental formulation within higher-dimensional theories rather than a low-energy effective description, we remain in the string frame throughout this work.

[3] See Chapter 13 of Ref. [24] for further computational details.

of the current equation, one obtains

$$J_{\mu}^{e} = J_{\mu}^{3} + \frac{1}{2} J_{\mu}^{Y}. \quad (9)$$

where can be deformed in the constants notation as

$$g\sin\theta_W = g'\cos\theta_W = e \quad (10)$$

The electromagnetic interaction (a $U(1)$ gauge symmetry with coupling e "sits across" weak isospin (an $SU(2)_L$ and symmetry with coupling g) and weak hypercharge (a $U(1)$ symmetry with coupling g') . We see that there is no convergence in the number of coupling constants and they merely related with each other thorough an "intervening factors" θ_W which can be determined by the experiment. Hence the so-called electroweak unification fails to unite the corresponding constants of the theories.

Theory of almost everything: gravity exclusion

Grand Unified Theories, or GUTs, seek to bridge the gap between the three fundamental forces in the Standard Model of particle physics: the strong nuclear force, the weak nuclear force, and electromagnetism. GUTs typically do not incorporate the gravitational force. The omission of this force can be approached from two perspectives. One perspective is to neglect gravity on the subatomic level, while the other viewpoint regards it as an effective force rather than a fundamental one.

The answer to whether gravity is considered an effective field or a fundamental force in the context of GUTs is not clear cut and depends on the specific GUT model being considered. Some GUT models treat gravity as a fundamental force that cannot be unified with the other three fundamental forces in the Standard Model of particle physics. Other GUT models treat gravity as an effective field, which emerges from the unification of the other three forces at very high energies. In summary, the treatment of gravity in GUTs is still an active area of research, and different models may treat it differently.

Beyond the standard model

The Standard Model was fully established by 1973 with all its constituent elements in position. During the 1970s, there was frequent reference to a comprehensive theory known as the unified theory, which amalgamated the electromagnetic, weak, and strong interactions into a consistent portrayal of matter particles and forces. The gravitational force remains the only force that has yet to be incorporated into a comprehensive quantum gauge field theory, despite numerous attempts to do so.

The pursuit of a more comprehensive unified theory beyond the Standard Model is a prominent area of interest for researchers. A notable focus in this endeavor pertains to the development of a quantum rendition of Einstein's general theory of relativity. A significant challenge associated with any research program in this domain is that the quantum gravitational effects magnitude is estimated to be exceedingly minute for any physical system that can be accessed experimentally, rendering them unobservable. However, the detection of gravitons, which are gravitational quantum particles, is expected to remain elusive for an extended period. In light of the aforementioned circumstances, it seems unlikely that any proposition positing a quantum theory exclusively addressing gravity would be amenable to empirical verification. It is possible that the principle of uniqueness could provide a solution, whereby there exists only a single consistent approach for quantizing general relativity. Regrettably, it appears highly probable that this assertion is invalid, as proponents of loop quantum gravity, $N = 8$ supergravity, asymptotic safety, and string theory each present a compelling argument that their respective research endeavors pave the path towards one or multiple coherent theories.

In the event that pertinent experiments are not available, a plausible approach to substantiate a theory of quantum gravity would entail the discovery of a comprehensive theory founded on principles that entail gravity as a corollary, while simultaneously yielding other distinguishable consequences that are more amenable to empirical testing. The prospect of string theory being capable of achieving this feat was a primary factor that generated enthusiasm among scholars circa 1984.

The theoretical framework of the Standard Model is founded upon the mathematical concept of gauge groups. These are collections of symmetries, e.g. mathematical transformations, under which a certain theory of physics is invariant. These groups are usually given rather non-descriptive names. For example, the symmetry group of Maxwell's theory of electromagnetism is called $U(1)$. Collectively, the group structure of the Standard Model is known as $SU(3) \otimes SU(2) \otimes U(1)$. The Standard Model posits that the $SU(2)$ symmetry undergoes spontaneous breaking, whereby its direct observation is not discernible in low-energy settings, but rather only in high-energy experimental contexts.

The inquiry into a more cohesive expansion of the Standard Model is expected to address a concise and familiar set of inquiries, which can be summarized as follows:

a. What is the rationale behind the choice of $SU(3) \otimes SU(2) \otimes U(1)$ and the determination of the corresponding coupling constants, which represent the magnitudes of the interactions between the fields?

b. What is the underlying reason for the behavior of quarks and leptons within the framework of $U(3) \otimes SU(2) \otimes U(1)$?

c. What is the underlying mechanism responsible for the spontaneous breaking of the $SU(2)$ gauge symmetry?

d. What is the reason behind the observed masses and other properties of quarks and leptons?

e. The only known successful answer to the first two questions on this list comes from grand unification; the idea that there is some larger symmetry group that breaks down to $SU(3) \otimes SU(2) \otimes U(1)$, i.e. has those (smaller) groups as constituents. The proposed concept utilizes the mathematical group $SO(10)$ and arranges the established quarks and leptons in a manner that conforms to its corresponding transformation properties. The inquiry remains as to why the group $SO(10)$ is selected, and a fresh issue of spontaneous symmetry breaking arises, namely, the mechanism responsible for the breakdown of the $SO(10)$ symmetry into $SU(3) \otimes SU(2) \otimes U(1)$.

The best answer we have to the last two questions is a rather unsatisfactory one. The incorporation of a novel elementary scalar field, known as the Higgs field, is implicated. This introduces problematic high-energy behavior into the theory. Since there are no symmetries that constrain the Higgs coupling to matter fields, one is left with a moderately large number of additional undetermined parameters, the existence of which renders the masses and other properties of matter as mysterious as ever.

Grand unified theories (GUTs)

Amidst the vast and mysterious expanse of the cosmos, a fundamental question has been plaguing humanity for centuries: what is the nature of the universe and how do its fundamental forces interact? Countless minds have grappled with this enigma, but it was not until the advent of Grand Unified Theories, or GUTs, that a glimmer of understanding emerged. These complex and elusive theories seek to unify the electromagnetic, weak, and strong nuclear forces into a single all-encompassing framework, shining a piercing light into the deepest and most profound mysteries of the universe. However, the path to such enlightenment is not for the faint of heart, as GUTs require a level of mathematical sophistication and conceptual abstraction that would make even the most seasoned physicist's head spin. Yet, for those who are brave enough to tread this path, the rewards are immense, as GUTs promise to reveal the secrets of the universe in ways that were once thought impossible.

The study of Grand Unified Theories (GUTs) commenced in 1974, in close proximity to the establishment of the Standard Model in 1973. As is mentioned, the mathematical concept of gauge groups provides the underpinning for the theoretical framework of the Standard Model $SU(3)\otimes SU(2)\otimes U(1)$. Hence, it is plausible to assert that a mathematical group which contains the standard model group as a subgroup has the potential to serve as a viable candidate for GUTs. Upon scrutinizing the consistency criterion, the count of feasible GUTs can amount to 15, namely:

$$SU(5), SO(10), E_{(6)}, F_{(4)}, SO(9), SU(5), SO(7), SO(8), SU(4), E_{(7)}, E_{(8)}, SU(8), SO(14), SO(18), SO(22).$$

The most basic among these theories, i.e, $SU(5)$, encountered a discrepancy with empirical evidence as they postulated the unobserved decay of the proton. Also, in this group, when one counts the generators, i.e, interactions/force carriers (24), it is not one expects due to standard model (12). The issue of coupling constant unification was successfully addressed by supersymmetric adaptations of GUT models. However, this approach introduced a fresh set of challenges related to the requirement of supersymmetry breaking. As of 1984, the absence of substantial advancements towards surpassing the Standard Model had initiated a sense of discouragement.

String theory: a forlorn landscape

The field of string theory has a four-decade long history and has undergone significant development, resulting in the emergence of several active sub-fields in both physics and mathematics. The literature in this field comprises a significant number of papers, often utilizing intricate and specialized mathematical techniques, thereby highlighting the considerable level of complexity involved. This circumstance poses a significant challenge in assessing the current status of the field and drawing definitive inferences regarding the efficacy of various concepts. This section will concentrate on a specific facet of string theory, namely the prospect of a comprehensive theory that encompasses both general relativity and the Standard Model. Also, this section aims to assert that although the aforementioned was the primary impetus for the surge of enthusiasm towards string theory in 1984, there exist compelling justifications to contend that endeavors to achieve unification through this approach are destined to be futile.[4] In contemporary times, a particular faction within the string theory community has responded to the challenges associated with string theory and unification by postulating the presence of a string theory landscape. The postulated landscape would render it unfeasible to derive empirically verifiable predictions from string theory. The deviation from the conventional scientific method, driven by a reluctance to relinquish deeply ingrained aspirations, poses notable hazards for the field of theoretical physics if it were to be widely accepted.

First superstring revolution

Prior to the mid of 70's, a limited group of physicists had been exploring string theories and their super symmetric counterparts. This was driven by the notion that these theories could potentially facilitate the amalgamation of the Standard Model and gravity. Quantization of string theory was a difficult subject, with the quantization procedure producing anomalies that violated the symmetries of the classical theory. After some time, it became evident that some of these issues disappear in the presence of a particular critical space time dimension, which was 26 for the non-super symmetric Bosonic string and 10 for the superstring. The 10-dimensional superstring has garnered significant attention due to its potential to yield a super symmetric Grand Unified Theory (GUT) that extends the Standard Model. One outstanding technical issue pertained to the potential emergence of an anomaly within the gauge symmetry of said theory. In the summer of 1984, Michael Green and John Schwarz demonstrated the resolution of a particular issue pertaining to gauge groups by utilizing the $SO(32)$ group. This development garnered the interest of Edward Witten, who subsequently devoted significant effort towards devising a feasible unified theory through the application of the superstring.

Similarly, there is also an anomaly cancellation computation that offers the crucial spacetime dimension of the superstring (ten). This was not the answer one sought (four[5]), so the search began for ways of making the other six dimensions unobservable. The most common method involved adding six extra dimensions to create a Ricci-flat Kähler manifold, also called a Calabi-Yau manifold. With such a choice, the low-energy field theory limit could have four-dimensional super symmetry, yielding the type of super symmetric GUT model regarded as the most promising extension of the Standard Model.

This speculative unified framework quickly attracted a great deal of interest, with numerous particle theorists deciding to begin studying string theory and working in this field. Nevertheless, from the beginning, there was no notably strong evidence for such a unified theory. The proposed string theory framework was capable of answering some questions that the Standard Model could not (why is there a particular number of space time dimensions? Why a specific choice of gauge group?), but it gave not the observed answers,

[4]See also [5] for more details.

[5]About $d=4$ spacetime, Hawking pointed out that one possible answer is the anthropic principle. Two space dimensions do not seem to be enough to allow for the development of complicated beings. There would also be problems with more than three space dimensions. The gravitational force between two bodies would decrease more rapidly with distance than it does in three dimensions. It seems clear that life, at least as we know it, can exist only in regions of space-time in which three space and one time dimension. This would mean that one could appeal to the anthropic principle, provided one could show that string theory does at least allow there to be such regions of the universe. And it seems that indeed each string theory does allow such regions.

rather much larger ones. As a result, one could apparently embed the Standard Model in a string model, but, suspiciously, all the questions that required answers were transformed into a new one: why this particular embedding?

Second superstring revolution

String theorists frequently use phrases like "We don't know what string theory really is" to describe the state of the field. They imply that there is no well-defined fundamental definition of the theory. Instead, we have various theories that are supposed to be approximations to the fundamental theory in certain limits, together with various consistency conditions that are assumed to hold in whatever the fundamental theory might be. Quantization of the classical string theory yields something basically equivalent to quantization of the theory of a relativistic point particle. From such a point particle theory, one can develop a more complete theory based on the so-called perturbation technique, but this is only an approximation of something far more fundamental, a quantum field theory. For some aspects of the Standard Model, such as high-energy QCD processes, perturbation theory provides a powerful computational technique. However, for others, such as the low-energy limit of QCD where strong interactions dominate, it becomes ineffective, requiring non-perturbative approaches.

The simplest method to develop a really basic nonperturbative version of string theory is to attempt to replicate the point particle situation and establish a string field theory; nevertheless, this approach has not yet produced a viable, consistent theory. 1995 witnessed the emergence of a series of concepts that provided a new direction for the investigation of what nonperturbative string theory may be. One part of these concepts concerned a variety of duality transformations connecting the several known ten-dimensional superstring theories. M-theory refers to the conjectural underlying nonperturbative theory that was hypothesized to reduce to superstring theories in a variety of limiting cases. There have been numerous more or less concrete definitions of M-theory, but none of them are entirely satisfactory.

One portion of the conjectural M-theory tale was the enlargement of the class of objects studied to include not merely strings, but branes. As strings move, they create a two-dimensional space known as the string's "worldsheet." In the perturbative string formalism, a string theory is fundamentally determined by the selection of a suitable twodimensional quantum field theory that resides on the world-sheet. In the late 1980s, a great deal of effort was expended to classify these field theories, which have a beautiful and rigid mathematical structure. Polchinski and others discovered around 1995 that these field theories must be studied in conjunction with a particular selection of boundary conditions. These conditions were known as branes. A fundamental example of a brane would be boundary conditions that fix the ends of an open string to specific spacetime points, and the term brane is sometimes used to refer to the collection of such points.

While M-theory and branes have raised a number of intriguing string theory-related questions, they have also made the string theory unification situation significantly worse. M-theory was conjectured to be something that united the known string theories in a unique (but still unknown) theory, but it needed the introduction of a whole new set of structures (the branes), which could be selected in many different ways. These new possibilities lead to a vast range of new possibilities for incorporating the Standard Model into string theory. Instead of eliminating six dimensions using a collection of invisibly tiny Calabi-Yau manifolds, one may arrange for our four-dimensional spacetime to exist as a brane inside ten-dimensional space. Through proper selections of branes, with acceptable relative locations and crossings, one may generate an even larger range of methods to incorporate the Standard Model in string theory than previously. At least initially, these extra choices did not seem to help with the moduli -stabilization problem.

Everything: physical or philosophical

A philosophical ToE would need to unite analytic and continental philosophy as much as is feasible or makes sense. It may be argued that issues such as "Why is there anything at all?" pertain more to metaphysics than to a philosophical ToE.

The "system building" approach to metaphysics aims to provide a comprehensive picture of the universe by offering coherent answers to all significant issues. Plato and Aristotle's ideas might be considered early instances of complete systems. In the early modern era (17th and 18th centuries), the system-building scope of philosophy is often associated with the rationalist method of philosophy, which is the way of deducing the nature of the universe by pure a priori reason. Leibniz's monadology, Descartes dualism, and Spinoza's monism are examples of works from the early modern era. Later theories include Hegel's absolute idealism and Whitehead's process philosophy. Nowadays, structural-systematic philosophy (SSP) is the subject. The SSP makes no claims to finality; rather, it seeks to be the finest accessible systematic philosophy.

Several philosophers disagree that philosophy should have such lofty goals. Some scientists believe that a ToE requires a more quantitative approach than philosophy; for example, Stephen Hawking argued in *A Brief History of Time* that even if we had a ToE, it would have to be a collection of equations. Gödel's incompleteness theorem is referenced whenever the search for a unified theory is discussed in mathematical manners. This theorem asserts that obtaining consistency with completeness is problematic. Every time we attempt to synchronize our theory with the physical world, we recede from completeness. Equally, it will be impossible to synchronize a ToE with the familiar world of physics.[6] Yet in addition to Gödel's theorem, there is also Rescher's argument.

Rescher's argument

Nicholas Rescher discusses what he believes to be the primary characteristics of a ToE, as well as an apparent obstacle on the path to such a theory.

Principle of sufficient reason: At first, as a premise the principle of sufficient reason, which, in Rescher formulation, asserts that every fact t has an explanation t'

$$\forall t \exists t' \rightarrow \left(t' \mathcal{E} t\right), \tag{11}$$

where $\mathcal{E}$ designates explanation, so that $t'\mathcal{E}t$ denotes "t ' explains t ". Afterwards, he argues that the most straightforward and natural design of a ToE $\mathcal{T}$ would provide it with two essential characteristics: comprehensiveness and finality.

Comprehensiveness states that whenever a fact t exists, its explanation may be found in $\mathcal{T}$

$$\forall t \rightarrow \left(\mathcal{T} \mathcal{E} t\right) \tag{12}$$

Finality implies that as a ToE, $\mathcal{T}$ has no further explanation:

$$\forall t\left(t \mathcal{E} \mathcal{T}\right) \rightarrow \left(t = \mathcal{T}\right) \rightarrow \left(\mathcal{T} \mathcal{E} \mathcal{T}\right) \tag{13}$$

Hence, the only plausible explanation for $\mathcal{T}$ is $\mathcal{T}$ itself.

[6] It should be emphasized that Gödel's theorem may be avoided in several ways, as stated in a talk presented by E. Siri at the 24th Bayan-Cosmology meeting.

Noncircularity: Rescher observes that it is evidently impossible to use a theory to explain itself; at the core of the conventional idea of explanatory adequacy, he adds, is a noncircularity criterion saying that no fact can explain itself

$$\nexists t \rightarrow (t\mathcal{E}t) \tag{14}$$

Comprehensiveness and finality, two crucial characteristics of a ToE, are in contradiction with the basic premise of noncircularity. A complete theory that explains everything must explain itself, and a final theory that has no further explanation must, according to the principle of sufficient reason, have an explanation. Hence, it must also explain itself.[7] Rescher concludes that any Theorist of Everything who is devoted to completeness and finality see noncircularity as "something that has to be jettisoned", which is incorrect.

The role of consciousness on ToE

David Chalmers claims that a ToE has to encompass consciousness. However, in his own words, "consciousness does not rationally supervene on the physical, and that a fundemental theory in physics would thus not be a ToE." Not only physical features and rules, but also phenomenal or protophenomenal attributes and psychophysical laws explicating the link between physical processes and conscious experience, he says, are required for a final theory. "Once we have a basic theory of consciousness to complement a fundamental theory of physics, we may have an explanation of everything," he concludes. It would not be easy to develop such a theory, he believes, but it should be doable in principle.[8]

Patchwork vs pyramid

Nancy Cartwright uses the metaphor of a "dappled world" to describe a world brimming with many items of varying natures. "The laws that describe this universe are a patchwork, not a pyramid," she concludes. There is no one set of rules with a simple, elegant and abstract structure of a system of axioms and theses. Different domains must negotiate with one another. Not knowledge of laws, but knowledge of the essence of things must be pursued. This shift in emphasis from mathematically expressed principles to the inherent character of things poses no threat to science. Its nature may reveal inherent regularity and order. Cartwright highlights a characteristic of science that is often overlooked by individuals seeking definite solutions to issues. The success of experimental research is contingent on the capacity to replicate experiments under identical circumstances elsewhere. Experiments provide artificial conditions in which one characteristic may be examined while others are ostensibly held constant. The settings of an experiment are a simplification of the complexity of the actual world, where other influences might interfere. In addition, scientific ideas determine what is to be considered noteworthy and what might be disregarded as "noise" The models employed by scientists to represent experimental conditions are theory-based and represent ideal circumstances.

Another contemporary philosopher of science concurs with Cartwright's approach. John Dupré denies that science could ever represent a single, coherent endeavor, emphasizing the world's tremendous variety. Rejecting the standard assumptions of contemporary science about law-governed and completely understandable structures, he defends what he calls "the chaos of things." His objective is to resist microphysical reduction, which he adds "has been generally connected with scientific unity."

It seems that Dupré equates resistance to reduction with the maintenance of chaos. However, maintaining a more diverse world may mean a persistent lack of order and, hence, intelligibility. Refusing to accept microphysical reductionism might jeopardize the whole scientific endeavor. The world must be comprehensible to people for science to advance.

Without reduction, the unity of science may seem to disintegrate into separate specialties. By isolating each field and contesting the dominance of physics, it may be argued that the scientific effort loses its unity and its purpose becomes unclear. According to Cartwright, "the picture of an ordered, deterministic, clockwork cosmos, with its origins in a certain concept of monarchical divine government, has strangely persisted despite our accomplishments."

Conclusion

The pursuit of a ToE remains one of the most ambitious scientific endeavors, seeking to unify all fundamental interactions into a single, coherent framework. Throughout history, numerous theoretical frameworks have been proposed, ranging from the Grand Unified Theories to string theory and M-theory. While each of these paradigms has provided significant insights into the nature of fundamental forces, none has yet succeeded in fully reconciling gravity with quantum mechanics. The limitations of existing models highlight the profound challenges of achieving a complete unification, prompting both physical and philosophical inquiries into whether such a theory is even attainable.

From a physical standpoint, the exclusion of gravity in GUTs and the immense complexity of string theory have led to skepticism about the feasibility of a truly unified theory. The landscape of string theory, with its vast number of possible solutions, and the difficulties in experimental validation pose serious challenges to its status as a ToE. Furthermore, alternative perspectives, such as treating gravity as an emergent phenomenon rather than a fundamental interaction, suggest that our understanding of unification may require a paradigm shift. Philosophically, arguments such as Rescher's principle of sufficient reason and Gödel's incompleteness theorem raise questions about the very nature of explanatory completeness, indicating that a ToE may be inherently unattainable or require a radical redefinition of scientific methodology.

Ultimately, the quest for a ToE may be a reflection of our drive for intellectual synthesis rather than a physically realizable objective. Whether such a theory will emerge as a final, comprehensive framework or remain an evolving set of approximations remains an open question. The interplay between physical theories, mathematical structures, and philosophical considerations suggests that a complete understanding of the universe may not lie in a singular theory, but rather in a dynamic and ever-expanding tapestry of interconnected ideas. Regardless of its ultimate fate, the search for a ToE continues to inspire profound scientific and philosophical inquiry, driving the frontiers of knowledge forward.

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[7]The use of trivial or self-evident reasonings is one method for evading Rescher's argument. If the ToE can be supported by them, then Rescher's argument becomes less persuasive. Moreover, according to Rescher's argument, if evidence from outside abstractions (such as experimental data) is also utilized in a portion of the ToE, that theory will no longer be the ToE. H. Manouchehri-Kousha is acknowledged for bringing this up.

[8] See [14] for more on the description of consciousness, life, and free will in ToE.

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