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TOWARD A COMPUTATIONAL THEORY OF EVERYTHING

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HIGHLIGHTS

- This paper proposes the computational theory of everything (CToE) as an alternative to string theory (ST), and loop quantum gravity (LQG) in the quest for a theory of quantum gravity and the theory of everything.
- A review is presented on the development of some of the fundamental ideas of quantum gravity and the ToE, with an emphasis on ST and LQG. Their strengths, successes, achievements, and open challenges are presented and summarized.
- The results of the investigation revealed that ST has not so far stood up to scientific experimental scrutiny. Therefore, it cannot be considered as a contender for a ToE.
- LQG or ST is either incomplete or simply poorly understood. Each of the theories or approaches has achieved notable successes. To achieve the dream of a theory of gravity and a ToE, we may need to develop a new approach that combines the virtues of these two theories and information. The physics of information and computation may be the missing link or paradigm as it brings new recommendations and alternate points of view to each of these theories.

ABSTRACT

The search for a comprehensive theory of quantum gravity (QG) and the theory of everything (ToE) is an ongoing process. Among the plethora of theories, some of the leading ones are string theory and loop quantum gravity. The present article focuses on the computational theory of everything (CToE). The author argues that the universe behaves computationally, by performing operations such as addition, subtraction, and multiplication. Computation seems to be a process by which space and time were formed and as a result of which matter, particles, and indeed everything in the universe, take form and grow. Computation, or natural computation, appears to be the universal mechanism that runs the entire universe. Based on the theoretical evidence and the empirical data from physics and theoretical computer science, the author has put forward the CToE as an alternative to string theory (ST) and loop quantum gravity (LQG), in the quest of the ToE.

KEYWORDS

Computation, Computational universe, Computes, Consciousness, Digital physics, Information, Loop quantum gravity, Postulates, Quantum gravity, String theory, Theory of everything.

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1. INTRODUCTION

In the last quarter of the twentieth century, there has been immense progress in developing a theory that is capable of describing natural forces within a single coherent framework: a theory that is able to encapsulate and develop the scientific models that unify quantum mechanics (i.e., very small things) with general relativity (i.e., very large things) and the theory of everything (ToE). Remarkable results have been achieved both in their applications and in the wider quest to understand the universe.

With the discovery of quantum theory and the ensuing development of the theory of relativity, humanity has benefited from the progress of physics and its applications. The standard model (SM) has been extremely effective. In the SM of particle physics, particles are considered to be point-like objects. One of its most successful achievement is the unification of the three of the four fundamental forces of nature – electromagnetic force, and both the strong and weak nuclear forces. However, the fourth fundamental force, gravity, has proved elusive owing to the disparities between quantum mechanics and the general theory of relativity. This quest has led to the search for a new theory that unites gravity and the three other fundamental forces.

During this search, several theories have been developed. Two of the main ones include superstring theory (ST) and loop quantum gravity (LQG). Proposes that subatomic particles are strings and are so tiny that they appear to us as points; this theory is the most promising candidate for a ToE. LQG is based on classical general relativity; one of its most important conclusions is that gravity should be quantized. However, despite the progress and achievements of the developed theories, there remain several unresolved issues. Simultaneously, alternative theories have been developed, or are in the process of being developed. Some of these include causal set, Euclidean gravity, topological quantum field theory (QFT), noncommutative geometry, and Penrose's twistor theory.

Additionally, a new theory that is gaining ground is called the E8 theory; this combines chaos theory and quantum information, and one of its main proponents is Sai Venkatesh Balasubramanian [1]. Another interesting ToE is led by David Deutsch [2], a great pioneer in quantum computation who is working on a new theory called Constructor Theory, which combines ideas from physics, cosmology, computation, evolution, and philosophy, to arrive at a new approach to describe the nature of reality.

Deutsch's theory attempts to account for several fundamental problems in physics. For example, why a few changes between chemical or physical phenomena are possible and some are most certainly not. A typical example of one of the issues he is trying to address is why something can dissolve in water but cannot clump back together. The point that Deutsch is making is that most leading theories do not adequately explain all aspects of a fundamental question; why are some transformations between states of being possible, while some are not? In asking this, he attempts to propose a framework built on the transformations themselves, rather than on the components.

In his noble effort to build his theory, Deutsch attempts to understand why such transformations would not be possible. According to David Deutsch [3], Constructor Theory shapes the basis of reality from which all the laws of physics emerge. The thought behind Deutsch's hypothesis is that all the laws of physics are expressible completely in terms of the physical alterations that are achievable and those that are impractical. Henceforth, this hypothesis contends that the laws of physics are the consequence of what is achievable and unfeasible.

David Deutsch [4] defines constructor as anything that can cause transformations in a physical system without undergoing any net change in doing so. He goes on to add that, "A transformation, regarded as being caused by a constructor, I call a construction." Constructors appear under various names in chemistry, physics, or biology. Some examples include a heat engine (a thermodynamics constructor), a computer program, an automated car (programmable constructor), and a living cell (in a human body, animal, or vegetable). However, all of these constructors do not currently appear in the laws of physics or chemistry. Ultimately, this important work might turn out to answer several fundamental questions in physics: for instance, which transformations are permitted, and which are not permitted.

Additionally, attempts to develop a Computational Theory of Everything (CToE) (a theoretical attempt by the proponents of the physics of information, computation, self-organization, and consciousness to build a ToE based on the concept of information and computation) have been spearheaded by the likes of Stephen Wolfram [5], Seth Lloyd [6], and Edward Fredkin [7].Their attempts, combined with advances in quantum computing, quantum information, cellular automata (CA) theory, self-organization theories, discrete physics, and holography have had an impact on the way we think about matter, atoms, and electrons. Furthermore, since the start of the 1990s, the role of information has become crucial in quantum mechanics; this is based partially on the realization that entanglement could be exploited to perform tasks that would be impossible in a classical world. This has led several physicists to ask themselves whether a new theory of quantum information is the way forward to achieve the dream of a ToE. This has led many theorists to outline a new way of understanding all physics as a form of computation.

Entanglement simply means that objects remain connected through time and space, long after their initial interaction has taken place. Instantaneous nonlocal exchange of information occurs through the medium of quantum correlation. This development, combined with the impact of the quantum computer and computation in physics, continues to play a key role in shifting the boundaries. This new view raises the prospect that the universe (a supposedly intelligent system), appears to behave like an intelligent computational system – a position known as the Computational Theory of Everything. It appears that the universe itself is the ultimate computer and that computation is taking place at every level of organization. The universe is a network of computational processes, and these processes create reality.

To reiterate, many of the favorable findings that support the case for a CToE have emerged from the studies that chart the intersections of computer science, discrete mathematics, quantum information, quantum computing, biology, psychology, consciousness, computation self-organization, and philosophy; this stresses the need for an interdisciplinary approach. The fundamentals of the ideas of computational theory over approximately the last twenty years have matured to a level where it might be possible to dream of a CToE. In this paper, I have put forward the five postulates of the CToE. Their theoretical understanding, combined with their possible applications in various fields of knowledge, appear to be capable of bridging the gap between quantum mechanics and relativity theory, thereby representing a potential candidate for a ToE.

This introduction has explained the need for this paper and the motivation, as well as the gap that has paved the way for this article. In the next section, a short review of the leading theories of quantum gravity and the ToE are discussed, pointing out their successes and achievements, including the challenges ahead, as well as their limitations. I go on to demonstrate that, despite their successes and achievements, a new approach or model is needed. Next, I move on to summarize the historical development of the physics of information and computation. This leads me to discuss the CToE in detail. Here, I aim to provide a more explicit explanation of how something may be described computationally. I go on to discuss the computational model based on the five postulates put forward, followed by a summary of recommendations and findings. In a nutshell, I argue that despite the successes and achievements of ST and LQG, there are a lot of limitations and challenges ahead. Therefore, a new direction is needed in the search for the ToE. The CToE might be a possible alternative.

2. THE PROBLEMS WITH OUR LEADING THEORY OF QUANTUM GRAVITY AND THE THEORY OF EVERYTHING

A short review is presented here on the development of some of the fundamental ideas of quantum gravity and the ToE, with an emphasis on ST and LQG. It is based on the works of Louis, J. et al. [8], Joseph Polchinski [9], Jason Shankel [10], Lee Smolin [11], Katie Silver [12], Sabine Hossenfelder [13], and others.

2.1 About String Theory

ST is a theory of quantum gravity (QG) that endeavors to combine the four fundamental forces of our universe into a single mathematically formulated law. The aim is, therefore, to answer several fundamental questions about our universe. In ST, elementary particles are replaced by tiny vibrating strings; these strings vibrate in ten spatial dimensions instead of the three we are familiar with. In this respect, ST generates everything in the universe that we see, touch, measure, or hear.

The proponents of ST argue that it is not primarily a theory of QG, as many researchers working in ST focus their research on other subjects not related to QG. We know that one of the tests of ST is that its foundation and validity are being questioned, as it has not so far been able to be experimentally tested. There is no doubt that of all the theories of QG, ST is the leading candidate and has emerged as the next great idea in physics.

2.1.1 Strengths, Successes, Achievements, and Open Challenges

ST cannot, at this stage, offer any falsifiable predictions. This is obviously one of the reasons why its validity is questioned, as it cannot be experimentally tested. However, according to its backers, there are hopes that the theory might reveal itself in some of the ongoing experiments at the Large Hadron Collider (LHC) and will prove once and for all whether ST is the holy grail of physics. Certainly, a comprehensive, inclusive, and rational theory should provide answers to countless of the queries about the nature of matter, life, and consciousness. However, one thing should be made clear: there is no testable ST of physics. The theory is still in the making, and it can be surmised that developing a testable ST will take many more years.

2.1.2 Strengths, Successes, and Achievements

- ST provides the tools and necessary ingredients with which to analyze and understand aspects of QFT. Quantum mechanics (QM) is the established framework for describing the world of molecules, atoms, nuclei, and their constituents. Its validity and successes are well documented. However, its application to describing relativistic particles requires the framework of QFT, which is characterized by *h bar* and the speed of light.
- The development of ST has led to a better understanding of QFT, quantum chromodynamics, and the quantum states of black holes (exemplified by the work of Leonard Susskind [14] and [15]; and Juan Maldacena [16], amongst others). The anti-de

Sitter/conformal field theory correspondence (AdS/CFT) and the Maldacena conjecture give insights into gauge theories (QFT). Additionally, STs have put forward some mathematical models of black holes that are similar to predictions made by Stephen Hawking.

- As a framework for QG, ST addresses important questions of cosmology related to the early universe and the physics of black holes. It tackles fundamental issues in cosmology and elementary particles, e.g., the unification of all forces, dark matter, dark energy, and supersymmetric particles.
- ST has driven major developments in mathematics; many mathematical techniques from ST can be applied in other areas of physics. Insights from ST have been used to tackle other problems in physics; for instance, ST has developed as a framework from which high energy physics can be understood. Furthermore, it provides a powerful tool with which to study field theories.
- ST provides new techniques and methods by which to understand aspects of quantum gauge theories, particularly the AdS/CFT correspondence. The development of these ideas has been incorporated in many branches of physics, from nuclear physics to condensed matter physics, where new insights have been gained. Some important successes include the provision of a microscopic basis for black hole thermodynamics and the discovery by Maldacena of the AdS/CFT correspondence, which seems to be a realization of the holographic principle of black hole physics.
- Mathematicians and many branches of mathematics have benefited from the development of ST. Many ideas and techniques from ST have been used in various branches of mathematics and have provided new insights and directions, as well as healthy interactions with various branches of mathematics and theoretical physics, such as fluid mechanics and condensed matter.
- ST has created a platform from which researchers in various fields, ranging from cosmology, mathematics, and condensed matter to particle physics, can communicate and exchange ideas, leading to new insights and the development of new techniques within these branches. This has promoted healthy interactions with various branches of mathematics and theoretical physics, such as fluid mechanics and condensed matter.

2.1.3 Challenges, Weaknesses, Deficiencies, and Incompleteness

Many physicists working in areas other than ST have been highly critical. They argue that ST has acquired an established status and exerts a strong influence in particle physics, cosmology, and other branches of physics. They base their arguments on two specific points.

- ST has gained its prominence without having found any empirical evidence.
- A theoretical complete formulation has yet to be achieved, despite 50 years having passed since the theory was proposed.
- To summarize, the challenges and weaknesses are as follows.
- The ST approach to QG and QFT is speculative, i.e., it has not yet been proven or disproven.
- ST remains highly theoretical speculation because so far it has not been corroborated by any direct evidence. Due to this, alternative approaches within the field of QG should be supported.
- ST is still an incomplete theory, as many of its aspects are yet to be fully understood. This constant has also been pointed out by Richard Dawid [17, p. 298].
- ST is detached from empirical confirmation and, despite five decades of intense work, is not yet a complete theory. Although many of the theory's aspects have been analyzed, a full understanding of the theory's structure has yet to be reached. It is

astonishing that, approximately 50 years after its creation, this theory has not yet reached the stage of being experimentally testable.

- Particle physics is dominated by concepts related to or inspired by ST. Additionally, many cosmological models are based on the approaches and ideas of ST. We know that particle physics is related to cosmology and the study of the structure of the universe. If ST is not the right approach, then the entire foundation of modern particle physics collapses, and new approaches are required; ST is our most trusted model.
- ST is treated as an established theory by its proponents; however, as ST is not supported by any direct empirical evidence, how can it acquire the status of an established theory? ST has obtained this status only through speculation and the solution of some of the conundrums of theoretical physics that we have mentioned. Conceptual and technical difficulties remain, including theoretical incompleteness and lack of evidence.
- ST, as it stands, has yet to produce results that are experimentally verifiable or, alternatively, falsifiable. It lacks testability and, as a result, many physicists argue that it cannot be considered as a contender to be a ToE.
- ST has a stranglehold on physics; most appointments in universities go to string theorists. Additionally, larger grants are allocated to them.
- There is currently no hope that any evidence will be generated soon, and unresolved issues abound. For some of the fundamental questions of physics, ST has provided elegant, impressive, and compelling answers. For others, it has failed to provide answers or result in any progress.
- The ongoing experiments at the LHC might reveal something about ST, including, perhaps, extra dimensions. However, for now, ST appears to be flawed and unverifiable.
- Many string theorists have been enamored by the mathematical beauty and elegance of M-theory (a theory that unifies all consistent versions of superstring theory) and have lost sight of the fundamentals.
- The considerable support for ST, to the exclusion of all (or almost all) other ideas or theories of quantum gravity, is not an ideal situation for physics.
- ST is not living up to its expected potential.
- High energy theoretical physics is dominated by ST.

2.2 Loop Quantum Gravity Summarized

ST, the most popular candidate for a theory of QG and the ToE, has, for a considerable amount of time, been questioned and its progress brought into question; this has paved the way for other candidates for a theory of QG. One of these is LQG, which was born out of general relativity (GR). This theory aims to match Einstein’s classical theory of gravity on a large scale; LQG aims to merge GR and QM. Several approaches to QG have been developed. This theory stems from the presumption that Einstein’s general theory of relativity can be quantized. This assumption has led to the establishment of several discrete methods, such as LQG and spin foam quantum gravity.

LQG takes Einstein’s theory in four space–time dimensions as its basic starting point. One of its assumptions is that at the very shortest distance (*Lp*), Einstein’s smooth geometry is replaced by quantum space or space–time and that the continuum is replaced by a discretuum. LQG is a nonperturbative approach to the QTG. It has modest aims; it does not attempt a grand unification, nor is it based on a reformulation of QFT. Its goal is to quantize Einstein’s gravity in four dimensions. In its original version, it has a canonical approach to QG; however, a covariant formulation of the theory, known as spin foam models, has been developed.

2.2.1 What is Loop Quantum Gravity?

LQG is a theory of quantum space–time. It seeks to outline the quantum properties of the universe and gravity. Why is it a theory of space–time? Simply because, from Einstein's GR, gravity is a manifestation of the geometry of space–time, it is essentially a property of space–time itself. As a theory of QG, it attempts, like ST, to unify QM with GR. Therefore, LQG attempts to formulate a theory of gravity based on Albert Einstein's geometrical formulation. It does this by developing a QTG based directly on Einstein's geometrical formulation, to formulate a quantum theory of GR and to quantize gravity in a nonperturbative (leading to a non-continuous structure of space–time at the Planck scale) and background-independent manner (i.e., the absence of space–time).

One approach to extending GR is to quantize space–time. In LQG, space is granular; the granularity is a consequence of the quantization. Space is discrete and is viewed as a fine fabric or network of finite loops. These networks of loops are commonly known as spin networks. The evolution of spin networks over time is known as spin foam. From an LQG viewpoint, both matter and space have an atomic structure. Jean Tate [18] informs us that LQG teaches us that space is made up of a network of quantized loops of gravitational fields known alternatively as spin networks. The quantization is at the Planck scale. The anticipated size of this structure is the Planck length, which is approximately 10^{-35} meters, as rightly pointed in [19]. The spin network approach models space–time as a series of pieces that are connected to each other. One of the ways to understand this model is to imagine it as a system of quantum nodes, as illustrated in figure 2-1.

It should be stressed once again that LQG is a QT of space–time that is background-independent and focused on geometry. It suggests that gravity, and consequently space–time, is quantized, i.e., space and time are made of quanta that make space–time granular. The size of each of these quanta is said to be the Planck length.

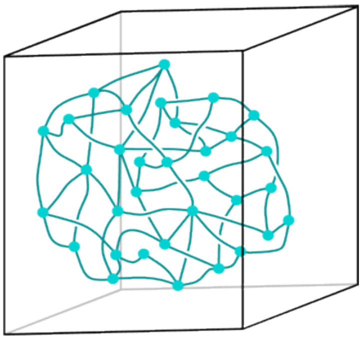


Figure 2-1. The fabric of space is represented as a spin network with nodes, as pictured here. (Reprinted with permission from T. Thiemann (FAU Erlangen), Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Milde Marketing Science Communication, Exozet effects)

2.2.2 Successes, Achievements and Challenges Ahead

Some successes of LQG include the following.

- LQG has been successfully applied to the study of black holes and has proved consistent with the Bekenstein–Hawking entropy formulation. It has been successful in calculating black hole entropy, the results matching predictions made by Stephen Hawking [20] and Bekenstein [21].

- It quantizes the three-dimensional spatial geometry of GR, and its applications to cosmology are successful in describing flat and homogeneous models.
- Its applications to cosmology suggest that the discreteness of physical space implies that the big bang of classical cosmology is replaced by the big bounce. It thus suggests a big bounce, rather than an infinite singularity, at the beginning of the big bang.
- LQG has yielded profound insights and has suggested a new theoretical framework for QG that provides new conceptual models and could possibly pave the way for a complete theory of QG. Nothing should be excluded since, with increasing collaboration, new technology, and progress in computing, the situation could change, and a QG experiment may become achievable within our lifetime.
- LQG has made some progress in matching Einstein’s classical theory of gravity on a large scale. Researchers have shown that LQG contains gravitons in the low-energy version of the theory. Additionally, further progress has been made in showing that the theory is as per Newton’s law of gravity.
- More work is needed to establish a solid correlation between LQG and GR; if this can be achieved, it may turn out that LQG is the best attempt at a QG theory.
- LQG does not have anything to do with a ToE because it does not include electromagnetism or nuclear forces. Perhaps the idea of producing a unified theory is not of concern to researchers in LQG.
- The challenges and flaws in LQG are approximately the same as those in ST; for instance, it lacks experimental verification. However, it is important to point out that LQG is closer to being able to be tested than ST; for example, using fine-tuned measurements of the big bang’s microwave background or observations by a gamma-ray telescope (GLAST).
- Both theories are not yet testable and are incapable of making physical predictions that are within the reach of current experiments. Simply put, there is a lack of an experimental basis from which to test various proposals. So far, no direct empirical evidence or corroboration of the theory has been found.
- Computations of the quanta of geometry (i.e., computation of the discrete eigenvalues of area and volume).
- It appears to be a productive platform for developing new mathematics that is simply a ground for expanding alternative ways of thinking about space–time and matter.
- Although questions about its consistency remain open, it is important to remember that all established theories were initially simply hopeful attempts.

2.2.3 Summary

The fact that ST has not so far stood up to scientific experimental scrutiny has prevented many physicists from taking it seriously. Why should it be supported so passionately? Its failure to make testable predictions leaves many with the feeling that it can only be a contender for a ToE and lead to a true picture of reality if it is backed by experimental evidence.

ST still has much to offer as it gives us a platform for investigating the behavior of QG. Its mathematical structure is very rich, which has led to insights and developments and has stimulated work in mathematics, leading to fruitful exchanges of ideas among mathematicians and physicists. ST remains a very exciting prospect and, as a tool, its mathematics and physical insights can be used to solve problems in other subjects. Unfortunately, ST is currently conspicuously incomplete, even though its basic idea is simple and startling. In learning about

ST, one discovers its rich structure, including extra dimensions, supersymmetry, gauge theories, dualities, holography, and gravity.

If the theory cannot be tested, it is our duty to make alternative arrangements, although I would say that, unfortunately, ST appears the most promising route so far for reconciling gravity and QM. However, it may turn out that alternative routes to QG may have to be considered as these might open the door to the unification of physics. Indeed, researchers should be supported in areas such as LQG, causal sets, digital physics (DP), and dynamical triangulations. Alternatively, if ST cannot be tested, there are only two choices: it must either undergo a fundamental change in the hope that it will become testable and progressive, or alternatively, it should be given up.

It may also turn out that our current understanding of the universe, based on classical general relativity and QM, is untenable. Much of our current understanding of space–time is encoded in GR, and much of the difficulty can simply be traced to the fundamental difference between space and time in special relativity (SR). These puzzles and limitations of our current theories point to a conflict between QT and our understanding of the structure of space–time. They also suggest the existence of a new, deeper theory that encompasses the successes and achievements of QT.

It is currently evident that we are a long way from having a satisfactory theory of QG, and any claim of a ToE is premature. It appears that each approach (LQG or ST) is either incomplete or simply poorly understood. Each of the theories or approaches has achieved notable successes. However, to achieve the final goal of a theory of gravity and a ToE, we may need to develop a new, more inclusive, complete approach that combines the virtues of these theories and information. The physics of information and computation may be the missing link or paradigm as it brings new recommendations and alternate points of view to each of these theories.

A broader, more inclusive, and open-minded approach is necessary to advance the search for both a QGT and a ToE. The attempts to build a ToE based on information and computation may act as a beginning platform and an up-to-date source for developing such a broader perspective. The next paragraph presents an overview of some of the numerous ideas, problems, and outstanding issues, both philosophical and technical. The article has so far presented the problems of a QGT and a ToE and has raised various issues that researchers are trying to address.

Information and computation are likely to provide us with insights into what types of features a formulation of a final theory may possess. This new and promising area of research gives ground to the hope that a unification may be possible sooner rather than later, in the form of a CToE. The following pages introduce the CToE, starting with the historical development of the field.

3. SUMMARY OF THE HISTORICAL DEVELOPMENT OF THE PHYSICS OF INFORMATION AND COMPUTATION

The discovery of QT, particularly the nature of its discreteness, such as the discrete energy levels, the Heisenberg uncertainty principle, the development of matrix mechanics, and, later, the advances in the theory of automata under the leadership of Von Neumann, led several physicists to speculate that space–time maybe discrete. Therefore, some physicists have had the goal of creating a whole new field called digital physics or discrete physics, where all physical quantities are discrete rather than continuous. Discrete physics, according to Feynman, is characterized by the quantities representing the state of a system being discrete values and finite in number. There have been many attempts by physicists moving in this direction, for instance, in 2003, Martin J. Leckey [22] put forward a proposal of aversion of modified quantum mechanics that arose naturally from a fully discrete physics; in this, he argued that all physical quantities are discrete rather than continuous.

Earlier attempts to establish a discrete foundation of physics failed. However, over the years, many of the problems that surrounded the development of a fully discrete physics have diminished due to recent advances in information theory, CA, loop quantum gravity, quantum information, and quantum computers. Additionally, the increasing power of computers has been partially responsible for inspiring a new generation of physicists and computer scientists in their attempts to fully develop a physics that is based on discrete models.

Above all, the influence of computers in physics has had far-reaching consequences in the way we view our universe. Quantum computation and the quantum computer have rekindled the possibility of building a fully discrete physics. Quantum computation, for instance, is a universal theory for discrete quantum mechanics. On the other hand, quantum computers are discrete systems that evolve by local interactions. Because of these developments, some within the physics community believe that the laws of physics will ultimately be understood to be a result of information.

In the mid-thirties, Alan Turing [23] and Alonzo Church, independently, proposed models of computation. Central to his 1936 paper, Turing proposed a thesis that stipulates: '[T]he "computable numbers" include all numbers which would naturally be regarded as computable.' (Turing 1936: 249.)” Alternatively, all computing devices can be simulated on a Turing machine.

Another key area that may have provided a boost to the physics of information and computation was initiated by John Von Newman [24], who is believed to have introduced the mathematical concepts of CA around the year 1948. The concept was introduced to study living biological systems and led him to introduce the idea of self-reproduction and to build machines known as kinematon to study living beings. A few years later, he teamed up with Stanislaw Marcin Ulam, who had already done some previous work and introduced him to the concept of cellular spaces.

Claude Elwood Shannon‘s [25] publication in 1948 of “A Mathematical Theory of Communication” in *Bell System Technical Journal*, as well as the many unresolved conceptual issues found in the foundations of quantum mechanics, led a number of digital thinkers, particularly physicists, to outline a new way of understanding in which all physics is described as a form of computation. This was partially due to the rapid growth of two fields of physics: quantum information and quantum computation. The rapid growth of quantum computation in recent years has heralded a novel way of understanding quantum mechanics; this type of computation supports the view that information is fundamental and should play a crucial role in our understanding of our universe. Figure 3.1 shows how the field of the physics of information and computation has emerged naturally from these various earlier theories.

Perhaps one of the most important works to date is credited to both Konrad Zuse [26] and Edward Fredkin [27] at the end of the 1960s. The most remarkable aspect of their work is the Zuse–Fredkin thesis that states that the Universe is a cellular automaton and assumes that the universe’s physical laws are discrete in nature [28][29].

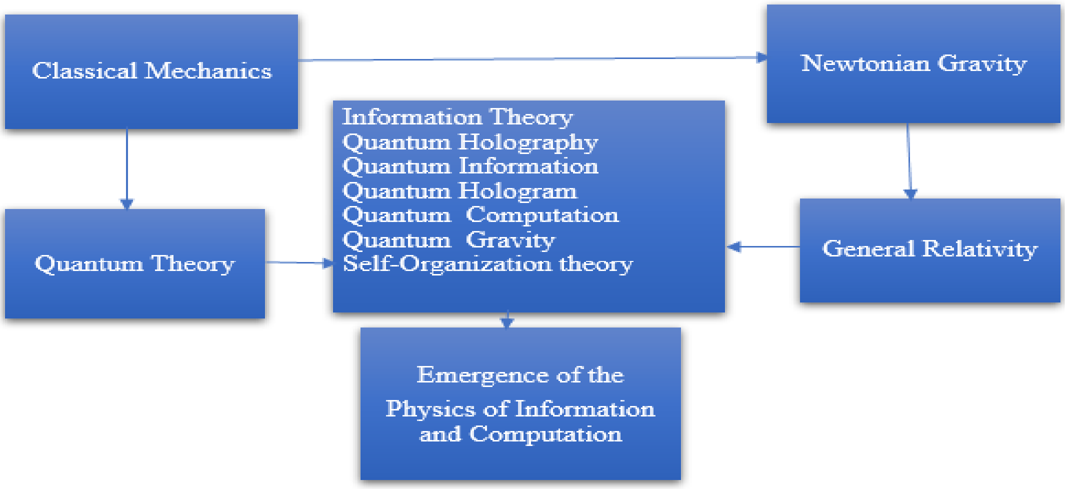


Figure 3-1. The physics of information and computation emerges in a natural way from classical mechanics, quantum theory, general relativity, quantum gravity, information theory, the holographic principle, etc. Adapted from Ediho Lokanga, *Digital Physics: The Universe Is a Programmed System* 2018

In the1970s, CA models became popularized by the work of John Horton Conway [30], then a Cambridge mathematician, following the publication of his article, “The Game of Life”, which appeared in the mathematical games section in the *Scientific American Column*. The Game of Life is traditionally played on an infinitely large grid of cells. In it, each cell can be either alive or dead. How the game evolves is very interesting: a special consideration is given to all of a cell’s surrounding neighbors and the decision should be made whether the cell should live or die, or vice-versa. This phenomenon is called birth, survival, and overcrowding or loneliness.

Since the 1980s and more recently, the widespread popularization of CA has been achieved through the work of Stephen Wolfram [31]; his work is based on empirical experiments using computers that have led to an extensive classification of CA models as mathematical models for self-organizing statistical systems. His colossal work led to the publication of his book called *A New Kind of Science*. In it, he has shown the link between CA and all branches of science, for example biology, mathematics, chemistry, and physics. Wolfram demonstrated, beyond doubt, the computational power of CA models.

However, critics of Wolfram have pointed out some limitations and the book has received its share of criticism. For instance, in 2003, Lawrence Gray [32] argued that Wolfram’s results lacked a rigorous mathematical test.

At the beginning of the 1980’s, scientific advances, as well as simultaneous breakthroughs in parallel computation, complexity, neural networks, and artificial intelligence, made us more aware of the role of computation and its implications for the future. Stephen Wolfram, through his investigation of CA, demonstrated the value of the CA paradigm. In the same period, research, and publications by Marvin Minsky’s [33] *Society of Mind*, in 1988, and Erik Drexler’s [34] *Engines of Creation*, in 1986, led to the idea of computation starting to be applied to mind and brain. Mind was redefined and represented as a computational system. The role of mind in a larger context started to be taken seriously, particularly in cognitive sciences.

In 1989, John A. Wheeler [35], perhaps the single most important pioneer and advocate of the physics of information of his generation, put forward the hypothesis that the universe is made up of information or binary digits (bits)in the presentation of his discourse entitled *It From Bit,* referring to a black hole, a word he coined. Everything in this universe, from particles and atoms to space–time, somehow derives its meaning, function, or existence from a series of choices (binary), yes/no, 0/1. This involves, he argued, a computational process. Jacob Bekenstein, later, brought these ideas to larger audiences with his excellent discussion on the physics of black holes and thermodynamics. A year later, in 1990, Jon von Neumann [36] explored and extended the idea of artificial intelligence, particularly the computational nature of the human mind with the publication of his book, entitled *Jon von Neumann and the Origins of Modern Computing*.

This view of the importance of information and computation seems to have gained ground since the 1990s. Andrew Steane argued strongly for an information–theoretic interpretation of quantum mechanics in his article entitled “Quantum Computing” in *Reports on Progress in Physics*:

Historically, much of fundamental physics has been concerned with discovering the fundamental particles of nature and the equations which describe their motions and interactions. It now appears that a different programme may be equally important: to discover the ways that nature allows and prevents information to be expressed and manipulated, rather than particles to move. [37, p.119][38][39].

In 2002, Seth Lloyd [40] explored the possibility of the universe being a computer and posed the question of how powerful it would be. His work led him, by analyzing the computing potential of quantum particles, to calculate the upper limit of how much computing power the entire universe has contained since its creation. The answer was 10120 operations. There have been differing opinions and interpretations of this number. According to some, it represents the performance of the ultimate computer, while others think it is simply the number of operations needed to simulate the universe on a quantum computer.

Similarly, another exciting area of research is in deoxyribonucleic acid (DNA) computers. Microprocessors made of silicon will reach their limits of speed and miniaturization and so a new material is needed to produce a faster computing speed. Millions of natural supercomputers exist inside living organisms, including our bodies. DNA molecules, the materials that make up our genes, have the potential to perform computation many times faster than any computers that have been built so far. There is a strong possibility that DNA might one day be integrated into a computer chip to create biochips that will make computers even faster. Therefore, there is some evidence that DNA molecules have been harnessed to perform complex mathematical problems. Experiments have demonstrated that DNA computers can store billions of times a greater number of information than our present modern-day computers.

To summarize, let us point out that theoretical results from both ST and LQG suggest that space–time has some discrete aspects at the Planck scale. The work of Bekenstein and Hawking on black hole thermodynamics has empowered us with new knowledge to reevaluate the continuous model and might be the most convincing proof for discreteness. In addition, the illustrious work of Gerardus 't Hooft [41] on CA as a model of discrete space–time physics suggests that the states of CA could be regarded as the bases of a Hilbert space from which quantum mechanics could be derived.

4. THE COMPUTATIONAL THEORY OF EVERYTHING

The idea that our universe is the result of information processing or maybe the outcome of a computational system is gaining ground. It has, over the last few years, evolved from key developments in the fields of physics, discrete mathematics, quantum computing, quantum information, philosophy, computer games, space–time, cosmology, etc. The CToE suggests that everything in the universe behaves as a computational system. Computation is a synonym for information processing. To compute is simply to process information. Generally speaking, it refers to the method of acquiring information from the outside world, processing that information, and then providing a result of the computational process. Information processing thus consists of three steps: data input, data manipulation/processing, and output. These three steps also seem to apply to all forms of computation in the universe.

Viewing computation as information processing simply means that anything that processes information, computes. It is also important to remember that not all computation is the same since computation takes place on different levels. Depending on the field, we can talk about biological computation, chemical computation, quantum computation, physical computation, or holographic computation, among others. All these computations appear to take place at different levels. According to Gordana Dodig Crnkovic [42], examples of computation include processes such as human cognition, cell metabolism, as well as the calculations performed by computing devices. Further examples of how nature or the universe computes are given in Figure 4-1.

This new view of understanding the universe has led to an increasing number and popularity of computational models. Many systems are given a computational description. Researchers in disparate disciplines, including physics, chemistry, biology, genetics, and psychology, have put forward various computational models. Two of the proponents among the many include Osman Yasar [43] and Giorgio Fontana [44]. This view has had a greater impact on those working in the field of biopsychology. For instance, a few scientists in the fields of biology and psychology have gone as far as to argue that the mind computes; this has in turn led to some scholars putting forward the Computational Theory of the mind (CTM). See for instance, James S. Albus [45] and Michael Rescorla [46]. The proponents of this model argue that the mind performs computation.

The CToE is thus a theory that models everything in the universe as performing a computation. The realization is that many phenomena in the universe are commonly attributed to the computational processes. It appears that the fundamental hypothesis of a CToE is that what occurs in the universe is underlined by a computational process and whatever phenomena take place are simply manifestations or results of a computational process, leading to the realization that the universe computes.

I would like to argue that a computational process is immaterial and occupies no space. However, this immaterial process determines the behavior of the physical universe, and, above all, the physical universe is required for the process to exists. One of the ways to understand the CToE is through the concept of zero-point energy (ZPE). One of the predictions of quantum theory is that empty space or vacuums contain residual background energy, i.e., ZPE. Quantum theory predicts that all of space must be filled with electromagnetic zero-point fluctuations or zero-point fields, thus creating a huge, universal sea of zero-point energy.

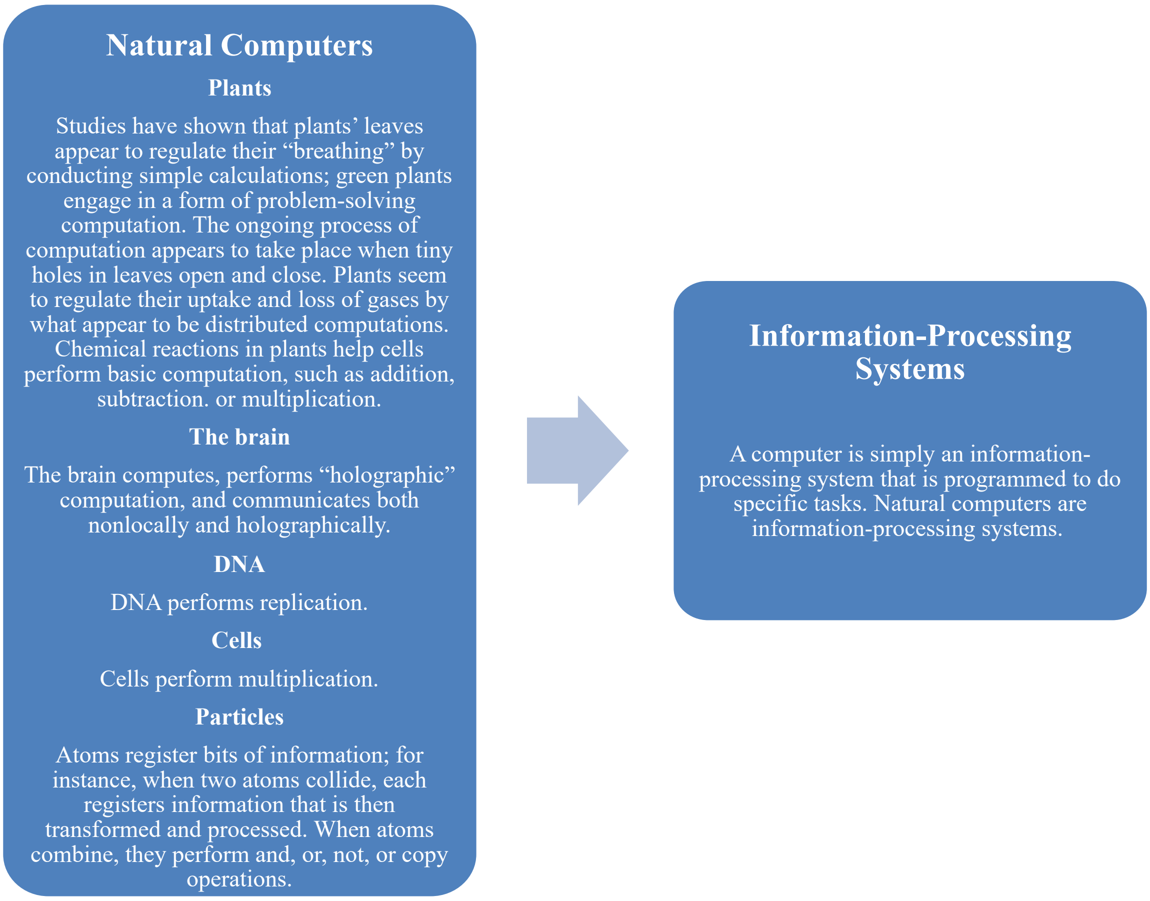
Why zero-point energy? In “Source of vacuum electromagnetic zero-point energy”, Harold E. Puthoff [47] explains the concepts of ZPE in detail. Furthermore, experiments have demonstrated beyond any doubt that at temperatures of absolute zero (-273 degrees Celsius), elementary particles continue to exhibit energetic behavior. As a result, all of space contains enormous zero-point energy. Matter and energy are continuously created and annihilated, and many physicists accept that the quantum vacuum is the underlying source of all matter and energy in the universe. It is clear, here, that each particle emits and absorbs packets of energy or information. The key is information processing. Every particle in the universe emits and absorbs information and energy.

Physicists have come to realize that all physical systems register information and simultaneously process it; this leads to the fact that the universe computes. Atoms register bits of information (such as, speed, temperature, position, or velocity); for instance, when two atoms collide, each one of them registers information that then is transformed and processed. What kinds of operations are then performed between atoms? When atoms combine, they perform and, or, not, or copy operations. This is well illustrated in the works of two scientists, Edward Fredkin and Tommaso Toffoli [48], who have been at the forefront of the studies of how atoms perform computations. Their work explains how atoms register bits, thus implying that atomic collisions obey the language of universal computation.

This line of reasoning is backed by the work of Seth Lloyd who argues that:

> Merely by existing, all physical systems register information. And by evolving dynamically in time, they transform and process that information. The laws of physics determine the amount of information that a physical system can register (number of bits) and the number of elementary logic operations that a system can perform (number of ops). The universe is a physical system. [49, p.1]

One of the most important ways to examine the validity of the CToE as an alternative to other ToE is to outline its key theoretical postulates. It is hoped that these postulates might offer or lead the way forward for a possible satisfactory resolution of the inconsistencies that exist between QM and relativity. The CToE is at best illustrated by its five postulates.



Natural Computers

Plants

Studies have shown that plants' leaves appear to regulate their "breathing" by conducting simple calculations; green plants engage in a form of problem-solving computation. The ongoing process of computation appears to take place when tiny holes in leaves open and close. Plants seem to regulate their uptake and loss of gases by what appear to be distributed computations. Chemical reactions in plants help cells perform basic computation, such as addition, subtraction. or multiplication.

The brain

The brain computes, performs "holographic" computation, and communicates both nonlocally and holographically.

DNA

DNA performs replication.

Cells

Cells perform multiplication.

Particles

Atoms register bits of information; for instance, when two atoms collide, each registers information that is then transformed and processed. When atoms combine, they perform and, or, not, or copy operations.

Information-Processing Systems

A computer is simply an information-processing system that is programmed to do specific tasks. Natural computers are information-processing systems.

Figure 4–1: Natural computers are information-processing systems

4.1 The Five Postulates of the Physics of Information and Computation

Here I introduce and discuss the five most important postulates of the physics of information and computation. I would like to look at them closely, considering the development of computers, computing, and physics. But first, let me state the five postulates.

Computation can describe all things: the progress made in the field of computer science, particularly on the hardware and software development, meant that everything around us and whatever we use and interact with, such as books, pictures, images, voices, music, etc, has been expressed into the basic notation of computation.

All things can compute: computers have been made from various materials, including human brains, Tinkertoy, steel, tungsten, electronic components, quantum particles, and DNA, to perform computations. This process is illustrated in figure 4-1.

Computation is universal: this sums up the first two postulates. Every constituent of the universe is manipulating information; atoms, molecules, and cells are constantly computing and transmitting information.

Universal holographic computation: this sums up the first three postulates. Humans, animals, plants, and particles communicate nonlocally and holographically. They are constantly computing and transmitting information holographically.

The universe is a self-organizing system: The universe is a self-organizing system; by transmitting information non-locally and holographically, the universe organizes itself, which means that it is a self-conscious organizing system.

4.1.1 Computation Can Describe All Things

The emergence of information and computation and recent developments has made it possible today to give computation a new meaning. Computation can describe all things. For instance, literary works, such as books, poems, and equations, are encapsulated into the basic notation of computation. On a higher order, digital-signal processing has made it possible to capture video (DVD) and music (CD) in better formats than before.

In information theory, any variable that can assume the value of 0 or 1 (yes or no) is called a binary digit or a bit. We can use binary digits such as 0 or 1 to transmit a set of instructions—for instance, instructions to make a binary choice are simply given by transmitting *yes* to suggest hot or *no* to suggest cold. Briefly, a number of bits of information can be encoded in a physical system; this is true when, for instance, a set of instructions in the form of *n* binary choices needs to be transmitted to identify the state of a physical system.

4.1.2 All Things Can Compute

Even though most things in our universe are entirely impossible to simulate with the resources we have (despite our powerful computers), there is an overwhelming conviction that everything in the universe can be reduced to simple algorithms. Everyday observations make us realize that everything—from climate change to the movement of stars, the twenty-four-hour cycle of the day, and the 365 days of the year—are essentially computational processes. This conviction and realization arise when one starts looking closely at nature, as well as playing with algorithms and simulations such as CA. The idea of universal automation—that everything is computation—makes you begin to see the wonder of computation everywhere you look.

Some branches of science embraced and recognized the nature and idea of algorithms long ago. For instance, the idea of DNA undergoing recursive algorithms has been recognized by biologists for a long time. Biologists see life as genetic information that is continually being computed (i.e., going through the process of computation). In chaos theory, quantum information, and quantum holograms, this idea is popular. Once one becomes familiar with a mathematically generated pattern, such as the Mandelbrot set, spirals, and fractals, one realizes that nature is continually performing digital computations.

4.1.3 Computation Is Universal

Following the work of Alan Turing, Alonso Church, and Emil Post, several authors and researchers have shown that, contrary to the overwhelmingly held view, computers are not universal. By the same reasoning, in an article entitled "Computation Is Universal, Computers are Not," researcher Selim G. Akl [50] has shown that "it is not true that a single universal computer can perform, through simulation, any computation that is possible on any other computer." In 2006, he pointed out that one of the many limitations of the Turing machine was the fact that it was incapable of performing any computation that required feedback from the outside world during the computation.

Several other researchers have shown that there is no universal general-purpose computer. Furthermore, the deficiency of the Turing Machine as a universal model of computation has been illustrated by several other scholars and is well documented in the works of Brian Jack Copeland [51][52] and David Deutsch[53]. Computation is universal, but computers are not. This combines the first two postulates into one. Every constituent of the universe is manipulating information; atoms, molecules, and cells are constantly computing and transmitting information.

4.1.4 Universal Holographic Computation

In 2018, the author [54], inspired by the work of several researchers such as David Bohm [55], David Bohm and Basil J. Hiley [56], Karl Pribham [57], Francesco Di Biase [58], and Francesco Di Biase and Mario Sergio Rocha [59], put forward the hypothesis of a quantum-holographic informational nature of the universe, that we are all connected (you, me, plants, animals, and minerals, etc.)—with all the information stored in the holographic patterns distributed in the entire cosmos and other universes in an indivisible, unbroken whole. This considers the basic mathematical property of holographic systems in which the information of the whole system is distributed in each part of the system: the whole is an emergent phenomenon of the parts. The quality of the whole is determined to a great extent by the nature of its parts or constituents. The parts or constituents reflect the nature of the universe, but the nature of the universe is also a reflection of us.

It follows from this that computing permeates the universe and drives every action. Everything in the universe, from atoms to molecules, is performing computations. Every single thing in the cosmos is manipulating information continuously. Brains, plants, humans, animals, nature, and the universe all perform holographic computations and transmit information holographically, whether they are aware of it or not. Everything in the universe computes and communicates nonlocally and holographically.

4.1.5 The Universe Is A Self-Organizing System

The origin of self-organization, like the holographic principle, has grown out of the limitations of the Newtonian paradigm and the reductionist nature of Darwinism. Both the reductionist paradigms have, so far, not been able to give a wholly satisfactory answer to many unanswered questions in science and technology. How did life evolve from matter? How did different types of living beings, such as animals or bacteria, come into existence? Why is a living being, such as a plant, able to self-organize itself? The need to study self-organization is fundamentally critical and may provide plausible answers to many of the enigmatic questions in science and explain the fundamental relationship between matter, energy, life, and information. It is probably a necessary preclude if we are to understand how other planets and the universe came into existence.

Understanding the behavior of complex systems may be a first step to better understanding the world in which we live. This is only possible by building models of complex and self-organizing systems. The modeling of a system and simulation help the understanding of these phenomena. Recent breakthroughs in the science of complexity have explained the emergence of new structures, such as the crystallization, the Benard phenomena, or simply the Belouzov–Zhabotinsky reaction or the swarming behavior that can only be understood through the study of self-organization. What is self-organization? Unfortunately, there is no agreement amongst researchers on how to define this subject. Various definitions have come from different fields of science. Self-organization occurs in many disciplines; it is found in engineering, physics, chemistry, economics, biology, social science, thermodynamics, information theory, mathematics, cybernetics, and synergetics, i.e., there are many definitions. Therefore, it simply depends on which subject the self-organization theory is applied.

For instance, Chris Lucas [60] explains that self-organization is the evolution of a system into an organized form in the absence of any outside intervention, whereas Francis Heylighen [61] argues that self-organization is simply the spontaneous emergence of global coherence out of local interactions. This combines the four postulates into one. The universe is a self-organizing system; by transmitting information non-locally and holographically, the universe organizes itself, which means that it is a self-conscious organizing system.

5. CONCLUSION

We have perhaps reached a crucial point in the search for a ToE; the idea of the CToE is gaining ground because many models are being developed and have been put forward. This is due to advances in computers, physics, etc., which have enabled the idea. The last few years have shown that some progress had been made and this is illustrated in the work of Wolfram, Seth Lloyd, Edward Fredkin, Gordana Dodig Crnkovic, Gregory Chaitin, Tommaso Toffoli, Norman Margolus, etc.

In five books, the author [62][63][64][65][66] has postulated the existence of a new hypothetical CToE that appears to be capable of bridging the gap between QM and general relativity, based on the five theoretical postulates of the physics of information, computation, self-organization, and consciousness. The CToE does not yet exist; this is just an attempt to put forward a model and that, at this stage, is simply a goal. The paper only asserts that a computational model of the universe is possible. The author has just suggested a direction in this immense landscape of theoretical physics. It is hoped that some researchers among us may or might arrive one day at a fully working model of the CToE.

Even if we are able to achieve this theory, a collaboration among scientists, engineers, and computer scientists will be required to test it. The scientific aspect must first be formulated, and later tested; this will require a major investment of funding and engineering work to implement the theoretical work. We are still a long time away, perhaps a decade, from having a widely accepted CToE. Instead, perhaps, it may take centuries to accomplish. However, it is also possible that remarkable research in the field of artificial intelligence and data science will yield important insights into many phenomena in science, including ST and LQG.

It is important to develop computational models that could generate universes similar to our physics. Some physicists may feel uneasy with the approach put forward in this paper and some have continued to play down any achievements or successes in this field. Sometimes the CToE is belittled, but if it is shown to be a valid proposition, physicists may no longer have much work to do, either willingly or unwillingly, and computer scientists, or those working in the interdisciplinary field of physics and computer sciences, may take over the search for the ToE.

To summarize, this paper has put forward a conceptual framework based on the five books of DP, written by the author. It is hoped that this framework might eventually lead to a CToE. To emphasize once again, this idea is based on a set of the five postulates of DP. The motivation of these postulates is to provide a starting point for a theoretical framework that might possibly lead to a CToE. The author has shown that to achieve the dream of a theory of gravity and the ToE, we need to develop a new approach that combines the virtues of these two theories and information.

REFERENCES

[1] Balasubramanian S V, (2015) "An Exceptionally Simple 'Theory of Everything' using Chaotic Quantum Information", Available at: https://pdfs.semanticscholar.org/ 18f2/51d15795c18dc29e58d484100856843c359b.pdf

[2] Deutsch D, (2012) "Constructor Theory", Accessed 06th November 2019. arXiv:1210.7439

[3] Deutsch D, (2014) "Deeper Than Quantum Mechanics—David Deutsch's New Theory of Reality", Accessed 14th September 2019. https://medium.com/the-physics-arxiv-blog/deeper-than-quantum-mechanics-david-deutschs-new-theory-of-reality-9b8281bc793a

[4] Deutsch D, (2012) "Constructor Theory", Accessed 06th November 2019. arXiv:1210.7439

[5] Wolfram S, (2002) *A New Kind of Science*, Champaign, IL: Wolfram Media, ISBN: 978-1579550080.

[6] Lloyd S, (2006) *Programming the Universe*, London, Jonathan Cape, ISBN: 978-1400033867.

[7] Fredkin E, (1990a) "Digital Mechanics", *Physica D*: pp254–70.

[8] Louis J et al., (2007) "String Theory: An Overview", *Lect. Notes Phys*. Vol.721, pp. 289–323.

[9] Polchinski J, (2015) "String theory to the rescue." Prepared for the meeting "Why Trust a Theory? Reconsidering Scientific Methodology in Light of Modern Physics", Munich, Dec. 7–9, 2015. Available at: https://www.kitp. ucsb.edu/ sites/default/ files/users/joep/Dawid15.pdf.

[10] Shankel J, (2012) "The Trouble with String Theory", Available at: http://io9. gizmodo.com/5890789/ the-trouble-with-string-theory.

[11] Smolin L, (2008) *The Trouble with Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next.* London: Penguin Books, ISBN-13: 978-0141018355.

[12] Silver K, (2015) "Will we ever have a theory of everything?", Available at: http:// www.bbc.co.uk/earth/story/20150409-can-science-ever-explain-everything.

[13] Hossenfelder S, (2016) "String Theory Meets Loop Quantum Gravity", *Quanta Magazine*. Available at: https://www.quantamagazine. org/20160112-string-theory-meets-loop-quantum-gravity/.

[14] Susskind L, (1995) "The World as a Hologram", *Journal of Mathematical Physics,* Vol.36, pp. 6377–96.

[15] Susskind L, (2003) "The Anthropic Landscape of String Theory", Available at: http://arXiv:hep-th/0302219v1.

[16] Maldacena J M, (1998) “The Large N-Limit of Superconformal Field Theories and Supergravity”, *International Journal of Theoretical Physics,* Vol. 2, pp. 231–52.

[17] Dawid R, (2006) “Underdetermination and Theory Succession from the Perspective of String Theory”, *Philosophy of Science,* Vol.73, No.3, pp. 298–322.

[18] Tate J, (2010) “What is Loop Quantum Gravity? “, Available at: https://www.universetoday.com/50702/loop-quantum-gravity/

[19] Technology Trends, (2016) “Loop Quantum Gravity”, Available at: https://www.primidi.com/loop_quantum_gravity

[20] Hawking S W, (1976) “Black Holes and Thermodynamics”, *Physical Review D,* Vol.13, pp. 191–7.

[21] Bekenstein J D, (1974) “Black-Hole Thermodynamics”, *Physics Today,* Vol.33, pp. 24–31.

[22] Leckey M, (2003) “Quantum Measurement, Complexity and Discrete Physics”, Available at: http://arxiv.org/pdf/quantph/0310033

[23] Turing A M, (1936) “On Computable Numbers, with an Application to the Entscheidungsproblem”, *Proceedings of the London Mathematical Society*, Series 2, Vol.42 (1936–37), pp. 230–265.

[24] McMullin B, (2000) “John von Neumann and the Evolutionary Growth of Complexity: Looking Backwards, Looking Forwards...” *Artificial Life*, Vol. 6, Issue 4, fall 2000, pp. 347–361.

[25] Shannon C E, (1948) “A Mathematical Theory of Communication”, *Bell System Technical Journal*, Vol.27, pp. 379–423 & pp. 623–656, July & October 1948.

[26] Zuse K, (1967) “Rechnender Raum (Calculating Space)”, *Elektronische Dalenverar Builung,* Vol.8, pp. 336–344.

[27] Fredkin E, (1990b) “Digital Mechanics: An Informational Process Based on Reversible Cellular Automata”, *Physica D* Vol. 45, pp. 1–3.

[28] Maerivoet S and De Moor B (2005) “Cellular Automata Models of Road Traffic”, *Physics Reports*, Vol.419, No. 1, pp.1-64.

[29] Zuse K, (1967) “Rechnender raum”, *Elektronische Datenverarbeitung*, Vol. 8, pp. 336–344.

[30] Gardner M, (1970) “Mathematical games-The fantastic combinations of John Conway’s New solitaire game ‘life’”, *Scientific American* (1970), pp. 120–123.

[31] Wolfram S, (2002) *A New Kind of Science*, Champaign, IL, Wolfram Media, ISBN: 978-1579550080.

[32] Gray L, (2003) “A Mathematician Looks at Wolfram’s New Kind of Science”, *Notices of the AMS*, Vol.50, No.2, pp. 200–211.

[33] Minsky M, (1988) *The Society of Mind*, New York, Simon and Schuster, ISBN: 978-0671657130.

[34] Drexler E, (1986) *Engines of Creation*, New York, Anchor, ISBN: 978-0385199735.

[35] Wheeler J A, (1989) “Information, Physics, and Quantum: The Search for Links”, In *Proceedings III International Symposium on Foundations of Quantum Mechanics*, Tokyo, pp. 354–68.

[36] Aspray W, (1990) *Jon von Neumann and the Origins of Modern Computing*, Cambridge, MIT Press, ISBN-13: 978-0262518857.

[37] Steane A, (1998) “Quantum Computing”, *Reports on Progress in Physics,* Vol.61, pp. 117–73.

[38] Danchin A, (2008) “Natural selection and immortality”, Available at: http://www.normalesup.org/~adanchin/ PDF_files/articles_08/biogerontology08.pdf

[39] Timpson G C, (2007) “Information, Immaterialism, Instrumentalism; Old and New in Quantum Information”, Available at: http://citeseerx.ist.psu.edu/viewdoc/download? doi=10.1.1.594.2257&rep=rep1&type=pdf

[40] Lloyd S, (2002) “Computational capacity of the Universe”, *Physical Review Letters*, Vol.88, No. 23, pp. 237901–237905.

[41] Hooft G, (1990) *The Cellular Automaton Interpretation of Quantum Mechanics*, Berlin, Springer, ISBN: 978-3319823140.

[42] Dodig Crnkovic G, (2011) “Dynamics of information as natural computation”, *Information*, Vol. 2, No.3, pp. 460–477.

[43] Yasar O, (2017) “Modeling and Simulation: How Everything Seems to Form and Grow”, IEEE *Journal of Computing in Science and Engineering*, Vol.9, No.1, pp. 74–77.

[44] Fontana G, (2006) “Travelling in the Computational Universe”, In *AIP Conference Proceedings*, Vol.813, No.1, pp. 1402–1408.

[45] Albus J, (2008) “Toward a Computational Theory of Mind”, *Journal of Mind Theory*, Vol.0, No.1, pp. 1–38.

[46] Rescorla M, (2017) “The Computational Theory of Mind”, *The Stanford Encyclopedia of Philosophy* (Spring 2017 Edition), Edward N. Zalta (ed.). Available at:<https://plato.stanford.edu/archives/spr2017/entries/computational-mind/>.

[47] Puthoff H E, (1989) “Source of vacuum electromagnetic zero-point energy”, *A Physical Review*, Vol.40, No.9, pp. 4857–4862

[48] Fredkin E &Toffoli T, (1982) “Conservative Logic”, *International Journal of Theoretical Physics*, Vol. 21, pp. 219–253.

[49] Lloyd S, (2002) “Computational capacity of the Universe”, *Physical Review Letters*, Vol.88, No. 23, pp. 237901–237905. Available at: http://cds.cern.ch/record/524220/files/0110141.pdf

[50] Akl Selim G, (2013) “Computation Is Universal, Computers Are Not”, Working paper. Available at: http://research.cs.queensu.ca/ ~akl/ COMPUTATION_IS_ UNIVERSAL_COMPUTERS_ARE_NOT/ Computation_Is_Universal_Computers_Are_Not.pdf.

[51] Copeland B J, (1998b) “Even Turing machines can compute uncomputable functions,” pp. 150–164. in Unconventional Models of Computation, C. Calude, J. Casti, and M. Dinneen, eds., London: Springer-Verlag.

[52] Copeland B J, (1998) “Super Turing-Machines”, *Complexity,* Vol.4, pp. 30–32.

[53] Deutsch D, (1997), *The Fabric of Reality*, London, Penguin Books, ISBN: 978-0140146905.

[54] Lokanga E, (2018) *Digital Physics: The Meaning of the Holographic Universe and Its Implications Beyond Theoretical Physics*, USA, CreateSpace Independent Publishing Platform, ISBN: 978-1979869515.

[55] Bohm D, (1981) *Wholeness and Implicate Order,* London, Routledge and Kegan Paul, ISBN: 978-0415289795.

[56] Bohm D. and Hiley B, (1993) *The Undivided Universe: An Ontological Interpretation of Quantum Theory,* London, Routledge, ISBN:978-0415121859.

[57] Pribham K. H, (1991) *Brain and Perception: Holonomy and Structure in Figural Processing*. Hillsdale, Lawrence Erlbaum Associates, ISBN:978-0898599954.

[58] Di Biase F, (2009) “A Holoinformational Model of Consciousness”, *Quantum Biosystems*, Vol. 3, pp.207- 220.

[59] Di Biase F. and Rocha M. (1999) “Information Self-Organization and Consciousness”, *World Futures—The Journal of General Evolution,* Vol.53, pp. 309– 327.

[60] Lucas C, (1997) “Self-Organising Systems FAQ”, Available at: http://www.mountainman.com.au/news97_h.html.

[61] Heylighen F, (2003) “The science of Self-Organization and Adaptivity”, Available at: http://pespmc1.vub.ac.be/Papers/EOLSS-Self-Organiz.pdf.

[62] Lokanga E, (2017) *Digital Physics: The Universe is a Programmed System*, USA, CreateSpace Independent Publishing Platform, ISBN: 978-1539959403.

[63] Lokanga E, (2018) *Digital Physics: The Meaning of the Holographic Universe and Its Implications Beyond Theoretical Physics*, USA, CreateSpace Independent Publishing Platform, ISBN: 978-1979869515.

[64] Lokanga E, (2018) *Digital Physics: The Physics of Information, Computation, Self-Organization and Consciousness Q&A*, USA, CreateSpace Independent Publishing Platform, ISBN: 978-1979869621.

[65] Lokanga E, (2019) *Digital Physics: Decoding the Universe*, USA, Kindle Direct Publishing, ISBN-13: 978-1099208133.

[66] Lokanga E, (2019) *Digital Physics: The Universe Computes*, USA, Kindle Direct Publishing, ISBN-13: 978-1099207143.