A Universe Made of Stories

By Philip Gibbs

Time comes into it.

Say it. Say it.

The universe is made of stories,

not of atoms.

These haunting words from "The Speed of Darkness" by Muriel Ruykeyser challenge us to question our reductionist instincts [1]. Is our conscious experience reducible? Does it merely emerge from physical laws deep inside the atom, or are the qualia of our thoughts fundamental in some way of their own? What does "fundamental" mean anyway?

What I will describe in this essay is my speculative view on the answers to these questions. It goes well beyond what current science knows with certainty. It may or may not be correct. Your different view may be more accurate than mine, but to find answers we first have to lay out the possibilities. My aim is to provoke your mind with ideas you may not agree with, but could find hard to dismiss entirely.

2017 marks the hundredth anniversary of Rutherford's successful experiment to split the atom. The protons and neutrons that he and others found inside have since been broken down into quarks and gluons. These partons and the electrons that float around the nucleus are in turn **emergent** at low energy from fields that pervade space, their intrinsic mass gifted by the Higgs. It has long been assumed nevertheless that the most elementary particles and their associated fields would be fundamental, indelibly tattooed onto the vellum of the universe. In recent years some theorists have come to doubt this. It is possible that the spectrum of particles we observed is just one of many physical options; a **stable vacuum** that the universe settled into by chance after the big bang. If so, then the physics probed in particle colliders is barely more **fundamental** in kind than the workings of biology that evolved from the initial chemical accidents of abiogenesis. This view is supported by theoretical frameworks such as string theory and loop quantum gravity that exhibit a **broad landscape** of possible stable vacua. We don't know if those theories are correct, but it is not unreasonable to suppose that the non-uniqueness of the vacuum is a feature of whatever theory of quantum gravity *is* correct. The **hypothesis** has been further bolstered by the observation that the laws of particles physics are **unnaturally fine-tuned**. To account for this we must accept that there is some scope for adjusting the parameters. The known particles cannot then be fundamental, but in that case **what is**?

Time begins at the big bang and ends at the singularity of a black hole. At its end points it must fade into some other unknown construct. The very idea of time evolution and dynamics breaks down. **Time then is not fundamental** and if time is out then so is space. Geometry, for all its grace and beauty, is just an emergent property of something more rudimentary. General relativity may be celebrated as the most aesthetically pleasing theory in physics, yet it must emerge from something deeper and possibly less appealing to our minds.

Quantum mechanics is not a specific physical law, not in the sense that general relativity and the standard model of particle physics are. It is a **framework within which laws sit**. As such it could be more fundamental than anything else we understand. Feynman delighted in the discovery that the process of quantisation can be interpreted as taking a weighted integral or **sum over all possible histories** of a classical field system. A history in human terms is just a real life story. This is where Ruykeyser's words become relevant in a fashion she could hardly have expected. There are many ways to interpret the lines of a poem, not all of them foreseen by the poet who penned them. The interpretation I want to use here is that the idea of quantisation as a sum over histories is **more fundamental** than particles or fields or even time and space.

Let's pause at this point, and ask what being "fundamental" means in physics. We know that some physical phenomena can be derived from a **more basic substratum**. Heat is a manifestation of the kinetic energy of atoms. Atoms are more fundamental than the laws of thermodynamics, but atomic physics in turn is derived from the interactions of more primitive components. **Is fundamentality then a relative concept with no absolute bottom, or is there a fundament of physical law which is not derived from anything deeper?** Does physics perhaps circle back on itself in recursive fashion? **"Fundamental" is an adjective to describe a level of reality that is not derived from anything else.** Fundamental laws are not in any way accidental or arbitrary. They must be as they are, because they could not be any other way. If such a level of reality exists, then how can it be explained? Do we just have to accept it as axiomatic? **Does it emerge out of nothing?**

These questions seem unanswerable but we must not accept defeat so quickly. The universe exists, so there must be answers. **Why would those answers be incomprehensible to us?**

Let's start again with a different question: **What is a story?** A story is a collection of **information** about **events** in some **world**. That world could be real or fictional. The elements of this definition are things that could be very fundamental. "Information" is an essential component of everything we can imagine. In physics the state of a system is described by information. No matter what kind of theory it is based on. **"Events" are things that can happen**. The spacetime manifold is defined as a set of events labelled by space and time coordinates. Events are also the interactions of particles, the **vertices of Feynman diagrams**. In general, events and information are the basic components of a story and the basic concepts of any physical theory.

Our contact with the universe comes through our **conscious experience**. That experience is also a form of story, a collection of information about events that enters our mind from the outside world. Everything we know about the world is perceived through our senses and understood through our rational thoughts. The mind itself is not fundamental. Neither are the biological processes by which it works, but the **principles of information** by which it functions are.

What makes our life story more real than the story of some character in a fictional novel picked up at the book shop? **Reality is relative to the observer.** Our universe is real to us because our story is directly connected to it through our senses. A thinking entity in any other possible universe is unreal to us, but to them their universe is real and ours is fictional. You may object. It's true that the information we have about our world is much more detailed than the information in any fictional story ever written, or even portrayed on film, but this is just a difference of **quantity**. In fundamental terms any story is real for its own characters. This is true whether the story has been written, or remains just a possibility not yet set down in words [2].

Information is everywhere. It crosses the universe in patterns or light, neutrinos and gravitational waves. The only thing that makes our minds more special than any other object that is changed by this information is our ability to gather and **organise the information** that comes our way. We can even react and act to collect more information through experimentation. In this way we build up knowledge of the state of our world and the laws by which it works, fundamental or not.

When we start reading a novel we have very little information about the imaginative world of the author. Each sentence gives new information that we **piece together** to create a picture of what happens in the story. Some things are unclear or incomplete. We don't expect everything to be known or knowable. How is the real world similar? You might answer that the difference is that in real life the universe **exists in every detail**. We only see the tiniest part of it but the rest is nevertheless out there. However, this is not true. The rules of quantum mechanics indicate that some things are uncertain. Only when we observe them do they become known. Our universe is detailed because our experience is **consistent** with not one, but **many stories**. It is a **cumulative effect** of all the possible storylines and the relationships between them. The distinction between the nature of **the real world** and an **unfolding story** does not seem to be as stark as we would like to think.

In standard quantum mechanics theory we describe a wavefunction which in principle covers the state space of everything in the universe at any given time. The past and present is seen as certain while the future is uncertain. This is really just an idealisation. The information in the wavefunction is conserved. The information we actually possess at any time describes just a small selection of the quantities in the universe that **could be known**. We can learn new things so this information is not conserved. The mind is not an isolated system. **There is uncertainty about past, present and future.**

Some facts about the future are better **determined** than events from the past. For example there is a great deal of **certainty** about when solar eclipses will happen for thousands of years into the future, but exactly what our ancestors looked like a few hundred years ago may be **undetermined** if no record of their actions remains. There is an illusion that things in the past are more certain than they really are because of our ability to **make records** of them. If we have a picture of our great great grandparents it provides detailed information about what they looked like. Can the appearance of other departed people be less certain, just because no pictures of them were kept? Of course it is not just the facts we know that are reasonably certain. Some things are **more** certain because they are the facts **most** consistent with all the information we have, even if we are not able to work out what those facts are. Even the distinction between what is certain or uncertain in the past is unclear.

What can we say about the laws of physics themselves? Are *they* at least certain? The physics we know including general relativity and the spectrum of particles in the standard model is not fundamental. These things too are therefore subject to some uncertainty. This does not mean that the laws of physics are created by our consciousness as we learn about them through experiment. The **range of physical laws** capable of underlying the universe we live in is very limited, so they have a very high degree of certainty whether we know them or not. Nevertheless, there remains a **fundamental element of uncertainty** in all things, no matter how slight.

Philosophers of physics discuss the **emergence** of the universe from nothing, but **what is nothing?** I like to provide an unusual answer to this question in terms of information. What would it mean to have **no information** about the universe, to know nothing about its laws or its history? It would simply mean that **all logically consistent possibilities** are still options. With no information the universe is the sum of all possible histories, described by all possible laws of physics. In terms of information **"Nothing" means "everything."**

When we are born our minds are already **shaped** by the laws of physics and by the history of **evolution**. The blank canvas of nothing has already been filled with information that narrows down the possibilities. As we grow and learn our observations change the wavefunction modifying the range of states, but this process is just a faint shadow of the full set of possibilities from which the laws of the universe emerged. These ideas make a lot of physicists uncomfortable, but quantum theory is enormously successful and the vast phase space of possible states is an unavoidable feature of its mechanics. We don't have to regard possibilities as realities. Remember, reality is relative. **Our reality is what we experience.**

Is it possible that the universe emerges from the **ensemble of all possible universes** with no other fundamental principle to guide its choice of physical law? Wouldn't we have to at least start by assigning some probability measure to the space of possible universes and wouldn't that be a fundamental and arbitrary choice without any basis? This is the **"great hitch."** Every philosophical argument about naturalness, multiverses or the anthropic principle seems to end here. Its proponents are apparently reduced to ridicule because they end in a place no better than where they started. That rebuttal is not necessarily justified. It is possible that our universe is based on some **universal behaviour** that can be understood within the mathematical analysis of the complex system of possibilities [3]. In particular, if the process of extracting information is **recursive** then the point of convergence may be independent of the starting point, including any initial choice of probability measure. As I said, the universe exists. We live our experiences. This should be taken a clue that there is an answer which is independent of any arbitrary fundamental choice.

This **principle of universality through recursion** means we can be bold. If you want to compute the square root of two by Newton-Raphson you must make an initial guess. A better guess gets you there quicker but the answer is the same. To understand the emergence of the universe we must take some starting point, but **the final result will depend only on the form of the recursion, which must be fundamental**. What then is this recursion and what is a good starting point?

Every possibility is assigned a probability. These are derived from the squared norm of a component in a wave function. Observables become operators, states become vectors, sets become functions, objects become morphisms. In physics we call this process "**quantisation."** It is closely related to the mathematical notions of exponentiation, abstraction and categorification. Even probabilities themselves may be uncertain, so they too are given a probability distribution. The process can be repeated to give us **iterated quantisation**, higher abstractions and n-categories. To understand the origins of physics we must define this recursion more precisely **in algebraic terms** and see how the physics of space, time and particles can emerge from it with specific features of our universe understood as processes of information collection. The fundamental laws of the universe are then **uniquely determined by invariance under quantisation** [4].

Second quantisation from a Lagrangrian is central to the quantum field theory of the standard model, but many theorists think quantisation and especially iterated quantisation has had its day, especially in the context of quantum gravity. The process of iterated quantisation I am talking about here will be an algebraic procedure without a Lagrangian. A Hamiltonian would be just one algebraic element that generates time progression. What we see in quantum field theory is just a shadow of the full structure of quantisation embodying the principle of summing over stories.

The universes in the ensemble of all possibilities **are not isolated**. There are relationships between them. Our individual experiences are represented by some subset of information that narrows down the possibilities, but it never reduces the list to one. The uncertainty principle makes sure of that. Sometimes people argue that our universe must be **a computer simulation** run by some beings in another world. They forget to take into account that **our information is incomplete** and any simulation would be just one possibility lost in the seascape of universes consistent with the sum total of our observations and experience.

The ensemble of possibilities together with these similarity relationships between them forms an **algebraic structure** in which relationships are morphisms between objects and can be composed algebraically. The process of reduction given specific information must therefore also be viewed algebraically.

Is symmetry fundamental? When I entered the discipline of theoretical physics in the late 1970s, symmetry had become a veritable panacea of the subject. The combined success of general relativity and Yang-Mills gauge theory, both built on principles of symmetry, fostered an expectation that further unification would follow from the discovery of more symmetry in physics. All theorists needed to do was identify the **universal symmetry** and the rest would follow from the principles of invariance and renormalisation. Supergravity in particular was touted as the best hope for a super-unified theory of all known physics. Four decades on this great hope seems to have subsided. Superstring theory never revealed an underlying symmetry principle. If space, time and the particles on which known symmetries act are not fundamental then how can their symmetries be?

It has always been my view that symmetry is not only fundamental, but that there is a **huge hidden symmetry** in nature that unifies the symmetry of spacetime and gauge theory. It also combines the **symmetry of multiple particles** in statistical physics under permutations with permutation symmetry over spacetime events. In my opinion the holographic principle that would explain the black hole information loss paradox is a clue to the existence of a "**complete symmetry**" where each degree of freedom in the universe is accompanied by a degree of symmetry in some huge Lie algebra [5]. This symmetry would be expected to exist in any pregeometric formulation of physics, albeit generalised through supersymmetry, quantum groups and higher-categories.

Symmetry is algebraic. It is classified by group theory and arises naturally from Galois theory in other algebraic structures. What is the algebraic equivalent of reduction through information? In group theory there is a well-known formalism that answers this question. Information about a group G would take the form of a set of equation relating elements of the group, or equivalently, equating a set of elements defined by group expressions to the identity $R_i(a_1, \dots) = e$. The most general group generated from a set of elements is a **free group** $F(a_1, \dots)$. The set of expressions generate a normal subgroup $N(R_i, \dots)$ in the free group and the group formed **modulo** this is the reduced group $G = F \,/\, N$ so that there is a homomorphism from F to G mapping N to the identity. Further information about the group would provide a new set of relations generating a normal subgroup of G which can then be factored over to form another smaller group. These ideas are fundamental to group theory and can be extended to other algebraic structures, for example the theory of ideals in algebraic rings. In category theory a generalisation can be formulated using coequivalence and epimorphisms. **The assimilation of information is an algebraic process of factorisation and morphisms.**

In algebraic terms then, the ensemble of all possibilities forms a freely generated structure in a **universal algebra**. Information about the world that forms part of life experience defines substructures and epimorphisms onto further algebraic structures that represent the possible universes that conform to the observed information. I want to provide a potted sketch of where these ideas lead mathematically. The interested reader is urged to search up the full details to more fully understand the implications.

What can be said of a free algebra? Isn't this a formless structure that gets us nowhere? Surprisingly that is not the case. We have to start somewhere so let's start with the free associative algebra. This is generated from a vector space V. Free associative products take the form of a sum over tensor products generating an infinite sequence of tensors of all non-negative ranks. This is known as the **tensor algebra** denoted $T(V)$. All associative algebras can be formed by taking quotients which impose relations on its generators, so there exists an algebra homomorphism from $T(V)$ to any other such algebra.

A Lie algebra can be formed from any associative algebra by using the commutator

$$[A, B] = AB - BA$$

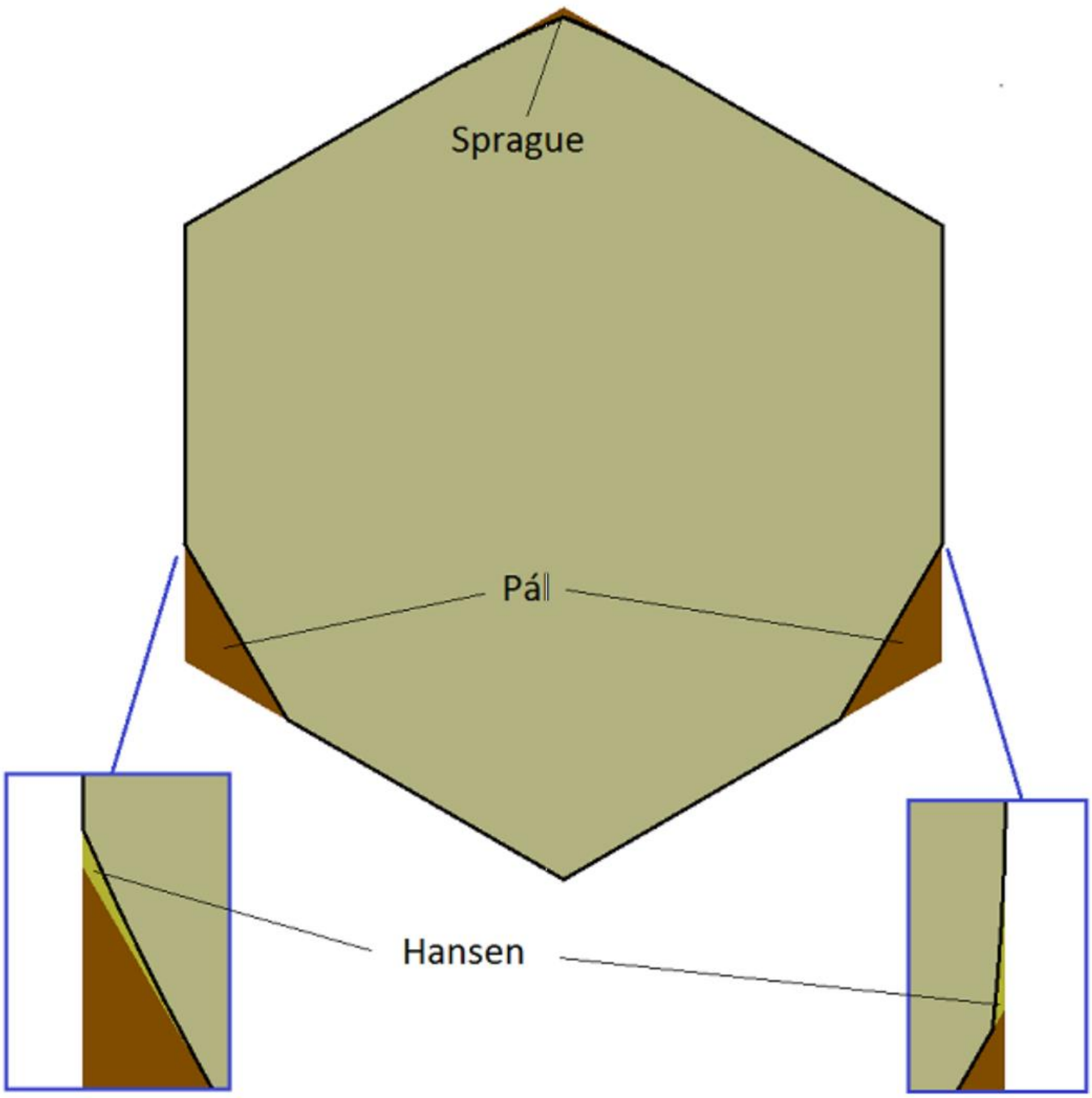
In the case of the tensor algebra the result of this derivation is the universal enveloping algebra of **the free Lie-algebra**. Just as the tensor algebra can be mapped onto any associative algebra, the free Lie algebra can be mapped onto any Lie-algebra, e.g. any continuous symmetry that appears in physics.

The free Lie-algebra is a remarkable structure given the simplicity and fundamental nature of its definition. It can be given a natural basis over **necklaces** which are discrete loop structures. The universal enveloping algebra promotes the basis from single necklaces to collections of necklaces. Therefore the free associative algebra $T(V)$ has a hidden structure defined over collections of loops. **The free Lie algebra is a necklace Lie algebra** [6].

There is another dimension of hidden structure for $T(V)$. Its properties can be extended through the recognition of a natural coproduct uniquely compatible with its product. A product like any binary operation is just a mapping from the Cartesian product $T(V) \times T(V) \rightarrow T(V)$. By linearity for algebras (distributive law) the Cartesian product can be replaced by a tensor product so multiplication becomes a mapping $T(V) \otimes T(V) \rightarrow T(V)$. A coproduct is a mapping that goes the other way $T(V) \rightarrow T(V) \otimes T(V)$. The universal enveloping algebra of a Lie algebra has a cocommutative coproduct of this type that is part of a Hopf algebra structure. Since the tensor algebra is the universal enveloping algebra of the free lie algebra it also has such a coproduct. This product turns out to be defined by a **shuffle product**.

This is already a lot of interesting structure coming out of something that started as a representation of nothing, but there is much more. The Hopf algebra on $T(V)$ has a natural homomorphism onto the Hopf algebra of paths through the vector space V. The homomorphic mapping is implemented using **iterated integrals** [7]. These integrals also relate to **polylogarithms**. The paths through a vector space can be interpreted as the paths in the Feynman path integral and the polylogarithms arise as amplitudes for Feynman diagrams. **A connection therefore exists between the structures of free associative algebras and quantum field theory.**

This mathematical picture is incomplete. In my opinion it can be extended by understanding better the algebraic meaning of quantisation. The product and coproduct are generators of an operator algebra mapping between general tensor products. This has a tree like structure similar to a Feynman diagram. The mappings from algebra to path integrals have their roots in motivic algebraic geometry as first explored by Grothendieck. These deep ideas need to be taken further. **Then the picture of iterated quantisations generating physics will be understood.**



The process of symmetry breaking is mysterious. Why are reflection and time reversal symmetries broken, but only by the **tiniest amounts**? Why does the Higgs mechanism break gauge symmetry at energies well below the natural Planck scale? I received some insight into this question when I was introduced to a hundred year old geometric problem posed by Henri Lebesgue in 1914. He had asked for the least area universal convex cover for all planar shapes of diameter one. The question has some natural symmetries. You are free to translate, rotate and reflect a shape to move it under the cover. Only the scale is set in absolute terms. Translation symmetry is immediately lost by the solution because a shape with translation symmetry in the plane has infinite extent. Full rotation symmetry would be retained by a circle but the smallest circular cover is far from the best solution. Gyula Pál discovered that a **regular hexagon with unit distance between opposite sides** is an efficient cover. This breaks the continuous rotation symmetry down to the discrete six-fold symmetry of the hexagon.

This became the first step in a short sequence of reductions that each break the symmetry further and by ever smaller amounts (see figure). Pál found that two corners of this hexagon could be removed by using the freedom of rotation to avoid those spaces. This reduced the area of the cover but then the rotation symmetry was lost. Only a bilateral reflection symmetry remained. 22 years later Roland Sprague noticed that smaller parts of Pál's solution were redundant even without further transformation of the covered shapes. Up to this point the option to reflect the shapes had not been exploited. There was a wait of another 56 years before Hansen found a way to use reflections that removed two tiny slivers from the shape with areas 4×10^{-11} and 8×10^{-21}. With these further reductions the reflection symmetry of the shape was lost, but only by the tiniest if amounts.

I find it striking that a simply stated geometric optimisation problem leads naturally to a solution exhibiting a hierarchy of symmetry breaking steps ending with a tiny loss of reflection symmetry. Perhaps we should not be so surprised after all that particle physics has similar features of spontaneous symmetry breaking. Isn't the low energy spectrum of particle physics also a result of an optimisation condition? Does this mean that fine-tuning is an illusion? No. **When the numbers help life exists we can call it fine-tuning, but the level of coincidence may not be as high as it looks**.

For Lebesgue's universal covering problem, Hansen's cover turned out not be the final word. In 2014 I was able to use computational methods to investigate the question further. It turned out that for 100 years mathematician's had missed a trick. If Pál's cuts are made at an angle differing from his by about 1 degree, then the freedom to reflect the shape can be used in a different way to reduce the area further [8]. If there is a further lesson to be learnt this, it is that the right mathematical tricks are not always obvious at first sight. Pál, Sprague and Hansen must all have thought that they had exhausted all the possibilities for further optimisation of the cover, but they were wrong. **Particle physicists should not give up on the hierarchy problem in particle physics just because they think they have tried everything**.

During my formative years at university, the leading lights of physics all preached that symmetry was the fundamental golden thread in the fabric of the universe. That has all changed. The prevalent view now is that symmetry is merely emergent [9,10]. Conservation laws are seen as approximate, even the law of conservation of energy is deemed to fail in general relativity. This point of view has arisen because gauge theories in different dual theories are not the same. Gauge symmetry can emerge in condensed matter and condensed matter theory has been a powerful inspiration in elementary particle physics, especially in the case of the Higgs mechanism. I don't accept this view. I think theoretical physics still has a lot to learn from symmetry. The problem is not that there is less of it at a more fundamental level. The problem is that there is so much of it that is hidden through symmetry breaking that physicists find the idea too incredible. I see the possibility of a huge underlying symmetry unifying gauge symmetries with permutation symmetry of particles and events. I find that conservation laws work perfectly in general relativity and I believe they will be significant component of our future understanding of the holographic principle. By continuing to follow the path of symmetry and quantisation I feel that I have gone from orthodoxy to heterodoxy without moving, yet my approach seems radical.

I expect to find this symmetry in a pregeometric meta-law that transcends spacetime, taking a purely algebraic form, only beyond that point will it be emergent, rising from immutable relationships between systems of information. From there our understanding returns full circle to the nature of our experience and our personal life stories.

The biggest difficulty faced by theoretical physicists of this generation is that positive experimental input on physics beyond the standard models is very hard to come by. That situation could change or it could continue for much longer. Without empirical data how is it possible to tell if the answer is string theory, loop quantum gravity, non-commutative geometry or something else? The theorists can still progress by working with the few clues they have, but success will depend on guessing correctly the answer to questions like 'what is "fundamental"?' If they don't know then they must be prepared to consider different philosophical options, letting the mathematics guide the way until the experimental outlook improves. If young researchers are all corralled into one pen it could turn out to be in the wrong place. The chances are they are going to be influenced only by the highest profile physicists. If those leaders say that symmetry is unimportant because it is emergent or that geometry is more fundamental than algebra, other possibilities may be neglected. It appears to me that there is a clear program that would combine the ideas of algebraic geometry with quantum field theory. It just requires mathematicians and physicists to bring their knowledge together.

References

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