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The Limits of Our Knowledge

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Despite the remarkable progress of science in the past century, there is more we don't know than we know. And to echo the wisdom of Donald Rumsfeld, there is even more that we don't know that we don't know.

Cosmic Issues

Here are some unknowns in our understanding of the universe. We have not identified dark matter. It dominates the matter around us by a factor of 5. Yet we are clueless as to its nature. The circumstantial evidence is strong.

It is weakly interacting, it surrounds us, it surrounds all observed large structures such as galaxies and clusters of galaxies. It fills the universe. Our best guess is that dark matter consists of elementary particles, as yet undiscovered. These particles occasionally collide with each other. Our best theory asserts that the origin of the universe began with a symmetric distribution of matter, and the relics of these today are the elusive dark matter. In this case, the dark matter particles are their only antiparticles. One consequence is the particles can annihilate, just as when a proton collides with an antiproton. The consequence is a tiny flash of gamma rays. In the vast depths of space, the cumulative emission of these gamma rays can be detectable by gamma ray telescopes.

No such effect has been seen, although there is at least one tantalizing hint of a detection. This is in the center of the Milky Way Galaxy where a substantial amount of dark matter has accumulated. The Fermi gamma ray telescope has detected a diffuse excess of gamma rays within the central few degrees. These follow the distribution of dark matter and support the idea that dark matter particles self-annihilate, rarely but still frequently enough to generate the high energy signal. The flux is right, the distribution on the sky is right, the distribution of gamma ray energies is right. But that's not enough to prove the signal is due to dark matter. To go further we need to see similar signals nearby dwarf galaxies that are teeming with dark matter. So far, we haven't detected such a signal. So, the jury remains out on the detection of dark matter.

Dark energy is even more pervasive. Dark energy is the only known explanation. This arises because dark energy is the accumulation of vast numbers of events in the vacuum. These comings and goings of pairs of particles and particles are so rapid that we can't measure them. But they effectively exert a pressure. The larger the volume considered, the more fluctuations there are, hence the pressure is larger. This is precisely the opposite of normal pressure, say from a gas. When expanded, the gas pressure decreases. This means that the pressure of dark energy is negative. Ordinary positive pressure is a form of energy and attracts just like gravity does. Dark energy pressure repels, and acts like antigravity. It accelerates the universe. Indeed, we measure an acceleration of the most distant galaxies.

This acceleration of the universe measures antigravity, and the only form we know of antigravity is dark energy. There is three times more dark energy than dark matter if we weigh our surroundings, yet it has no attractive gravity, so it is completely structureless. It is uniform in space and according to our best measurements it doesn't change in strength as we look back in time. So here is a phenomenon that only manifests itself in the recent past, as the density and pressure of ordinary matter decrease with the expansion. Galaxies first began to accelerate when dark energy became dominant, when the universe was about half its present size. Since then, acceleration of the distant galaxies has been manifest.

Biological matters

What is life? According to NASA, it is largely physical chemistry: 'Life is a self-sustained chemical system capable of undergoing Darwinian evolution." And NASA will go wherever it is to be found, along with the Chinese Space agency and the European Space agency, among others. The next space race is beginning, with the Moon as the first stop, and Mars eventually to follow.

Life began in a cosmic soup of amino acids shielded from ultraviolet light and extreme temperatures. The combination of cells needed to trigger cellular growth into the first primitive organisms is exceedingly rare, but complexity is not an impenetrable barrier. A bottom-up evolution is envisage-able, as many short cuts are possible once catalysts play a role.

Let's be a little more specific. About 4 billion years ago a very complex process began on Earth. It contained catalysts such as proteins protected by a membrane. It contained DNA to store information. It was able to transform an external source of energy such as sunlight. It was protected from extreme radiation, such as ultraviolet or high energy particles. It formed cells that could divide and receive instructions. Organisms, initially single cells, then multiple cells, develop and adapt to increasing levels of complexity.

One needs a planet that is neither too hot or too cold, in surroundings capable of diverting asteroids, that has an abundant supply of carbon, liquid water and an oxygen-rich atmosphere. The route to the simplest forms of life is via replication and reproduction of cells. Life is a transition from physics and chemistry to biology. There is no resolution of the crucial question, whether the inevitable endpoint of evolution is life as we know it. All we know is that its origin happened at least once, on the Earth. Life is more than just a random mix of chemical elements. One could never reproduce the vast number of combinations of molecules required to end up with a strand of DNA. There is not time enough in the universe if randomness reigns. Autocatalysis is the key, even if we don't fully understand how this works.

Where perhaps the real barrier arises is in the origin of consciousness. Biologists have no understanding of how consciousness arose in living matter. Emergence is the key concept, perhaps stimulated by environmental complexity, to the development of intelligence. But how this operates, we simply don't know. *One of the most astonishing things in the physical world is the way that mind emerges from matter. Atoms…form stars, rocks, oceans, planets, amoebae, mice, whales, the human brain. Somehow the brain enables creation of Bach concertos, supercomputers, jumbo jet aircraft, roast lamb, the Mona Lisa, the rules of chess, global warfare, Einstein's theories of relativity, the Eiffel Tower, Shakespeare's sonnets.*
George Ellis, *How Can Physics Underlie the Mind?*

Reductionism
There is an unending and lively debate on the origins of life. It is the most profound of debates, and one that raged for millennia. It involves scientists, including physicists, chemists, biologists, astronomers and even neuroscientists. It involves philosophers. It involves theologians. And it is a debate that is as unresolved today as much as it was in 5000 BC. What has changed is our language, from writing poetry about Nature to reducing the observed universe to a series of beautiful equations, inspired by physicists Albert Einstein and Erwin Shrödinger among others.

It is more than assembly of matter. It is more than the equations of physics. It is more than chemistry or physics or biology. In the words of Stephen Hawking, *what is it that breathes fire into the equations and makes a universe for them to describe?*
Stephen Hawking, *A Brief History of Time*

This involves some additional element of complexity that we are currently striving to understand. The missing link is hidden in nature. It involves both random permutations and environmental pressure. There are innumerable examples of animals with characteristics that have evolved in response to the environment. But chance is involved too, otherwise evolution is too slow. One classic example is the divergence in marsupial life, some 60 million years ago, which demonstrates how an element of chance played an initial role, later followed by similar environmental pressures, to produce parallel sequences of animals. According to Jacques Monod, *all* *that matters in biology is chance and necessity.*

And finally, our origins should be understandable. There should be no need to appeal to unknown physics or chemistry or biology unless there really is no alternative. There need be no hidden mysteries beyond the gates of science to be elucidated. *All human action…comes from complex interactions between memes, genes and all their products in complicated environments. There is no truth in the idea of an inner self inside my body that controls the body and is conscious.*
Susan Blackmore, *The Meme Machine.*

And beyond our actions, the entire panoply of human behavior and experience should emerge. How this happens is a mystery, but the evidence cannot be denied. The scientist who co-discovered the helical structure DNA once famously wrote: *You, your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nearbv cells and their associated molecules.*
Frances Crick*, Astonishing Hypothesis: The Scientific Search for the Soul*

So speak most scientists. But there are holdouts. And their reservations are echoed by many non-scientists. One main stumbling block is purpose. Is there more to life than random choices and survival, or chance and necessity? What are we here for? Are we mere creatures of our environment or is there something more to life?

Cosmology provides a new perspective. The vastness of the universe, its trillions of galaxies, each containing trillions of stars and planets, take us far from a human-centered vision. Randomness seemingly prevails. *The more the universe seems comprehensible, the more it also seems pointless.*
Stephen Weinberg, *The First Three Minutes.*

But there is order in what we observe. This encourages diverse points of view. Some seek solace in alternatives, beyond the laws of science, including physicist/theologian John Polkinghorne. *From its own unaided resources, natural science can do no more than present us with the contrast of a finely tuned and fruitful universe which is condemned to ultimate futility.*
John Polkinghorne, *The God of Hope and the End of the World.*

Others are happy with the unlimited potential of computing and artificial intelligence. Cross a certain threshold and more can emerge than is injected. This is how many scientists understand the origin of consciousness and self-awareness as primitive creatures evolve in complexity.

The Holistic View of Free Will
One issue that immediately comes to the forefront of any discussion about whether we are more than just an assemblage of molecules is the matter of free will. Is all that we will ever build or think preordained by our DNA content and our environmental history? Choice and free will may not exist, they are illusory, in a reductionist perspective. For example, psychologists have argued that the unconscious may reign, and what is apparently free will becomes illusory.

One also has to add an element of chance, that's for sure. like the throwing of a dice. Randomness is at the very core of physics, on the quantum level. As one builds up in scale, from the microscopic to the macroscopic, there is no longer this element of uncertainty in the physical laws. But there is always some residual effect that impinges on our behavior. Think Russian roulette. Its radioactive counterpart, of potentially cancerous radiation emitted say by radioactive decays over a nuclear isotope half-life of many thousands of years, following a Chernobyl-like disaster, strikes at random.

Even this is not enough for those who refuse to accept such limitations on our liberties of expression or even survival. They appeal to a higher level. Some call this emergence. On the medical front, this might be "miracle" cures or recoveries, unexplained by prior experience. Such higher order effects lead to emotions, to neuroses, to love, to poetry. *My choices are constrained by the laws of physics, my genetic inheritance, upbringing and education, the social, cultural, political and intellectual context of my existence….all our choices are caused. The question is how? We have free will*

because we are creatures of mind, meaning ideas, not just matter.
John Horgan, *Scientific American*

Beauty
And not far behind is that of beauty. Is this concept something unique to the human brain? The ultimate meaning of life may be embodied by beauty. Whether there is any absolute significance to this in a scientific perspective is far from clear. Concepts of beauty differ over the centuries and between continents. Poets revel in this discussion, despite the fact that much of beauty is in the eyes of the beholder. *Beauty is truth, truth beauty, - that is all ye know on earth, and all ye need to know.*
John Keats, *Ode on a Grecian Urn.*

And beyond words, there are emotions. There are intangible aspects of beauty that seem far removed from the reach of reductionist science. It is difficult to imagine a computer of the future expressing these thoughts. *I watch the niece, who is very beautiful, transformed into melancholy grace, into modesty, into a gentleness without word…she raised her eyes to mine and seemed to smile…I sense the mysterious presence of the soul, it fills me with the peace of silent realms. I have seen the shining light,*
Antoine de Saint-Exupery, *Flight to Arras*

From Beauty to Science
Or is the beauty intrinsic to nature, without need of human accolade? Physicists regard beauty as a guiding principle for unlocking the secrets of the universe. Beautiful ideas are akin to works of art or musical scores. The greatest scientists, from Galileo, Newton and Maxwell to Bohr and Einstein, saw virtually infinite beauty in physics, including symmetry, harmony and truth. We anxiously await a future genius to come along with a beauty-inspired Theory of Everything, or at least for the Large Hadron Collider to discover truth in supersymmetry.
Quantum reality has revealed that the world of everyday matter…embodies concepts of extraordinary beauty...built up from atoms that are… tiny musical instruments. In their interplay with light, they realize a mathematical Music of the Spheres that surpasses the visions of Pythagoras, Plato, and Kepler.
Frank Wilczek, *A Beautiful Question: Finding Nature's Deep Design*

Beauty-inspired seeds were sown by the ancient Greeks, from the fundamentals of geometry and music to chemistry. The music of the spheres, perhaps the hum from the orbits of celestial bodies whose periodicities echoed a musical harmony only heard by Pythagoras, inspired his followers to develop mathematical harmonies between beauty, music, mathematics and science. Numbers governed all, from octaves to isosceles triangles.

Geometry via perspective revolutionized classical then Renaissance art, and geometry via the curvature of space revolutionized our understanding of gravity as Einstein showed. Beauty, implemented by da Vinci, Blake and Dali among others, united art, biology, chemistry and physics. The search for symmetry generated enormous rewards in science, a gift that kept on giving throughout the centuries.

The patterns of magnetic lines of force were mapped out by nineteenth-century scientist Michael Faraday in an elegant display of empirical physics. Faraday went on to show that moving magnetic fields generate electric fields, and it was this discovery that motivated Maxwell to develop his theory of the equations of electromagnetism. These epitomized a fundamental symmetry, allowing a magnetic field in motion to generate an electric field, and vice versa. Both propagate in intimate alternation through space to produce waves of light and all colours of the rainbow. The equations also predicted the invisible — that electromagnetic waves would propagate through space at the speed of light but at frequencies beyond perception by the human eye. Inspired, Heinrich Hertz discovered radio waves, invisible frequencies of electromagnetic radiation. Beauty had succeeded far beyond any intent of Faraday's imagination.
Wielding the sword of beauty to refine scientific thought has a remarkable heritage. One grand success is the theory of general relativity. It could so easily have gotten so very ugly. A centuries-old anomaly in the orbit of the planet Mercury led many astronomers towards the hypothesis of an as yet undiscovered planet Vulcan

within Mercury's orbit that accounted for the observed orbital precession. But Einstein put beauty first in his concept of a new theory of gravity. He came along with a compellingly beautiful explanation in 1917 that he was able to confront with the ultimate test of a daring and visionary experiment. In the dreary climate of 1919, the aftermath of the First World War, worldwide headlines greeted the successful verification of one of his key predictions the bending of light rays by gravity.

Our understanding of modern physics, and in particular the nature of elementary particles, was to undergo a similar revolution., This took however half a century to build the machines needed to test the new theory. One triumph is the standard model of particle physics, whose symmetries led to the prediction of the Higgs boson. Indeed, the quantum core of modern physics, the entire zoo of elementary particles, stems from beautiful thoughts, framed by appeals to symmetry. The most successful example is the Eightfold Way, named by Murray Gellmann after Buddhism's eightfold path, which reorganized the menagerie of elementary particles, from neutrinos and electrons to quarks, into the octets of the core theory of matter, leaving space only for the last missing member, the Higgs boson, predicted in 1964 and finally discovered at CERN in 2012

But not all bits fall into place. Beauty is subjective. Many scores of particles, almost all short-lived, have been discovered by colliding protons together at ever higher energies; you are hard-pressed to see beauty in that. Now the search is on for a unifying principle to take us back to simplicity. The great challenge of future physics will be to find evidence for the most beautiful idea of all, supersymmetry, which unites particles containing mass with the quanta that carry the fundamental forces of nature. At the beginning, the universe was completely symmetric. Some physics process, conjectured by Andrei Sakharov, that involved the arrow of time and decays of elementary particles, created a minute asymmetry between matter and antimatter. Only today, once the dominant radiation along with its relativistic particle-antiparticle pairs has redshifted away, does the asymmetric component of matter totally dominate; we live in a universe of matter, where fortunately antimatter is exceedingly rare.

Not that supersymmetry is immune from criticism. This theory has some 120 adjustable degrees of freedom, arbitrary numbers that need to be assigned. Some may find this lack of elegance the antithesis of beauty, although the situation is partly redeemable thanks to the enormous efforts of experimental particle physics in measuring many of these numbers. So, at the end of the day, only a handful remain to be assigned. New, and inevitably expensive, experiments will be needed to finally close the circle. At present, only one real issue remains in finding supersymmetry, the holy grail of particle physics: how high do we need to go in energy to seek its elusive signature by smashing particles together with the Large Hadron Collider at CERN, or its likely successor in Europe or Japan or China?

Occasionally the search for beauty has led scientists astray. Ptolemy's epicycles that described planetary motions and the five Platonic Polyhedra that enabled Kepler to account for the relative distances of the five then known planets from the sun set science back for centuries. Modern data likewise debunked Fred Hoyle's steady state Universe. And even particle physics, with its grand hopes of unification, offers no insight into serious cosmological problems such as why unknown dark matter is six times more abundant than ordinary matter.

The most recent example is string theory, the compellingly beautiful union of mathematical simplicity with quantum theory, particle physics and gravity. The persuasive advocates of string theory have provoked an ongoing controversy: can a theory be so beautiful that we award it scientific accolades for its capacity to synthesize existing knowledge, without a single empirical test? Or without grounding truth is it destined for the scrapheap of history?

Persistent voices insist that ultimately a theory of physics must lead to experimental verification. Newton was emphatic about this: empiricism is core. Nobel laureate Frank Wilczek would like us to believe that empiricism is the search for truth. If truth and beauty are indeed inseparable, the circle is closed. That at least is where supersymmetry will fall or rise victorious. Physicists hope for the latter, although one must wait at the very least for an entire new generation of unprecedentedly powerful particle colliders to attain the dream of a unifying theory. And perhaps much longer.

From Super Intelligent Artificial Intelligence to Alien Life

Humanity has manifested intelligence, superior to that of animals, for perhaps 100,000 years. But the human brain is limited by its size. It has some 100 billion nerve cells or neurons, with about 16 billion in the cerebral cortex. These make some 100,000 connections with other neurons. We call these connections synapses, tiny electrical pulses, generated by chemical neurotransmitters. In all, our brain has about a thousand trillion or 10^{15} synapses at any instant. Of course, it's less active if we are sleeping, by about 20 percent.

Research on brains is often limited to animals. The mouse is a well-studied example with about 70 million neurons and about a trillion synapses. Experiments with microscopic cameras reveal its brain activity as the mouse moves around. The human equivalent is just a scaled-up version. Which takes us to the ultimate question: is a mouse conscious? If it is, even at a limited level, then human consciousness would seem to be an inevitable consequence of natural Darwinian evolution.

Simulating a human brain presently is at the limit of our current computing skills. The world's fastest computer, the Summit IBM machine at Oak Ridge in Tennessee, in the USA, occupies an area amounting to two tennis courts, with some 27,000 state of the art graphics processors. It operates at 10,000 trillion flops, or 10^{16} operations per second. This is comparable in power to the human brain. Indeed, our fastest computers now routinely outperform humans in chess and in the even more demanding game of Go.

If one can build a computer with comparable circuitry to the brain, would it achieve consciousness? This seems likely to me, though I am not a neuroscientist. However, there are some simple arguments to be made. One difficulty may lie in reproducing the brain. The speed of synapses is equivalent to a frequency of 200 Hertz. That at best limits the human reaction time to a about 10 milliseconds. Computers are much faster, by a factor of at least ten million. So, shouldn't it be a piece of cake to emulate the human brain? Already, philosopher Nick Bostrom reminds us of humility: *the adult human brain stores about one billion bits—a couple of orders of magnitude less than a low-end smartphone.*

Here is the problem. Intelligence can be enhanced, seemingly size and complexity count. Add more brain cells and synapses, then intelligence increases. But there is a complication. It's a highly nonlinear operation. Neurons are arranged in long strands linked by thousands of cells. This nonrandom arrangement makes it difficult to evaluate the odds of duplicating the brain. Nevertheless, our computing power will multiply enormously in the future and greatly facilitate artificial brain construction.

And then we run into another challenge. Intelligence is reducible perhaps to the number of synapses. But consciousness is not sufficiently well understood to make any such claim. Maybe it's a critical threshold effect. Above a certain number of synapses, a brain becomes self-aware. That's the beginning of consciousness. But we are from verifying this hypothesis with any experimental procedure.

When? This could happen very soon. The technology is already here. It's just a question of miniaturization, from a tennis-court-sized super-computer (the world's fastest today) to one that fits inside the human brain.

Within a few decades, machine intelligence will surpass human intelligence, leading to… technological change so rapid and profound it represents a rupture in the fabric of human history. The implications include the merger of biological and nonbiological intelligence, immortal software-based humans.,

Ray Kurzweil, *The Singularity is Near*

But even this timescale is tiny compared to what awaits humanity.

Let's look ahead to a million years from now. Even that is a mere wrinkle in time, compared to the 4 billion years remaining for our sun. Artificial Intelligence will certainly result in computers that can outperform any human brain within decades. The prospects of our obsolescence in favour of artificial brains are increasing, perhaps arriving within centuries from now. Refined technology will be key to achieving this. Harnessing the atoms as work horses provides the ultimate construction tool. Nobel physicist Richard Feynmann invented the concept of nanotechnology: *We can arrange the atoms the way we want, the very atoms all the way down!...we will get an enormously greater range of possible properties that substances can have, and things we can do…if we go down far enough, all our*

devices can be mass produced so that they are absolutely perfect copies of one another.
Richard Feynmann, in *Artificial Life.*

Despite these limitations, the potential for achieving nanotechnology goals is vast. Nanotechnology could provide quasi-immortality and revolutionize construction: *Such products… might roam through our bodies, invading cancerous cells and rearranging their DNA, might swarm as a barely visible metallic sheen over an outdoor construction site... in a few days, an elegant building would take shape. Every hour, entire factories no larger than a grain of sand might generate billions of machines that would look like a mass of dust streaming steadily from the factory doors.*
Eric Drexler*, Engines of Creation*
We are still a long way from achieving this technology. Nanotechnology on this scale is currently reminiscent of the world of science fiction. And many authors are skeptical. *The nanotechnology dream of constructing an artificial self-assembling atom-manipulating device currently resembles a form of postmodern alchemy.*
Gary Stix, *Scientific American.*

Still we have millions, even billions of years ahead of us. And there are certainly exoplanet twins of the earth that have a billion years advance on us. On such a longer perspective. by any of the usual evolutionary criteria, there may not be any role left for a human. For one thing, Bostrom continues, *when we consider scenarios stretching significantly into the second half of this century and beyond, we must take into account the probable emergence of a generation of genetically enhanced populations….the feasibility of cognitively enhanced humans adds to the plausibility that advanced forms of machine intelligence are feasible.*

There are immense intellectual prospects once we go beyond the limitations of the human brain. This could be beneficial. Here is the upside: *Let an ultra intelligent machine be defined as a machine that can far surpass all the intellectual activities of any man however clever. Since the design of machines is one of these intellectual activities, an ultra intelligent machine could design even better machine ... and the intelligence of man would be left far behind. Thus, the first ultra intelligent machine is the last invention that man need ever make.* Intellectual achievements would follow that could greatly extend our current frontiers of knowledge, in fields well beyond those of science. We have far to go: *The tardiness and wobbliness of humanity's progress on many of the "eternal problems" of philosophy [and science] are due to the unsuitability of the human cortex… our most celebrated philosophers [and scientists] are like dogs walking on their hind legs.*

Another dimension of progress might be in the hugely expanded role of leisure activities as machines liberate us from menial tasks such as work. Unimaginable hedonistic pleasures could await us: *an AI that has hedonism as its final goal... would like to tile the universe with matter organized in a configuration that is optimal for the generation of pleasurable experience… Such tricks could greatly increase the quantity of pleasure producible with a given amount of resources.*

Of course, science fiction has been remarkably prescient. Perhaps we have a human habit of recalling the more successful predictions. Some authors preach gloom with the inexorable advancement of science and especially of artificial intelligence. There are good aspects and there are bad aspects of nanotechnology. If we ever arrive in the remote Nano-future, the outcome could be catastrophic for humanity. Here is a nightmare vision of what might await us. There is a pending confrontation between the triumph of nanotechnology or descent into the swamp of grey goo. Here is the downside: *Before the prospect of an intelligence explosion, we humans are like small children playing with a bomb…Human individuals and human organizations typically have preferences over resources that are not well represented by AIs. An AI might therefore be more likely to pursue a risky course of action that has some chance of giving it control of the world. AI might also be able to produce a detailed blueprint for how to bootstrap from existing technology (such as biotechnology and protein engineering) to the constructor capabilities needed for high-throughput atomically precise manufacturing that would allow inexpensive fabrication of a much wider range of nanomechanical structures. Oulr demise may result from the habitat destruction that ensues when the AI begins massive global construction projects using nanotech factories.*
Nick Bostrom, *Superintelligence*
But why not move our Nano-factories into space. Let's do the construction and pollution there. That way, we can we preserve the environment, and indeed the Earth. That way, we can live on a perpetually green planet. Of course, this might still not be enough. Even if we don't mess up the Earth, we are bound to run into a catastrophic extinction event from an asteroid impact in the foreseeable future.

Microscopic to Macroscopic, Bottom-Up to Top-Down, Life Is Both

There is more to life than algorithmic complexity. Even ultra-intelligent supercomputers may come up short of injecting the breath of life. The missing ingredient may not be computable. Listen to the wisdom of a molecular biologist: *Beneath the calm, ordered exterior of a living organism lies microscopic chaos, molecules continuously crash into each other. Powered by energy, microscopic molecular machines work to create order out of the chaos. Tiny electrical motors turn electrical voltage into motion, tiny factories custom-build other molecular machines, and mechanical machines twist, untwist, separate and package strands of DNA. Life emerges from the random motions of atoms…*

Peter Hofmann, *Life's Ratchet: How Molecular Machines Extract Order from Chaos*

I leave the last word to one of the 20th century's greatest scientists and communicators of science who explored the laws of physics on all scales, from infinitesimal to cosmic. The universe is not simple. Its complexities however are finite. There is no fundamental reason to be pessimistic about the outcome. Wisdom will prevail. We simply need to connect the strands of the cosmic web that underlies our longing for hope and beauty, along with our human brains, to the fundamental laws of physics and the associated algorithmic drive for perfection and immortality. This encourages us to look forward to a future of profound understanding. *Which end is nearer to God? Beauty and hope, or the fundamental laws? We have to look at the whole structural connection of the thing…all the sciences, all the efforts of intellectual kinds, are an endeavor to …connect beauty to history, to connect history to man's psychology, man's psychology to the working of the brain, the brain to the neural impulse, the neural impulse to chemistry, and so forth, up and down, both ways. And today we cannot draw a line all the way from one end of this thing to the other. And I do not think either end is nearer to God. To stand at either end is a mistake. To stand with evil and beauty and hope, or with fundamental laws, is a mistake. It is not sensible for the ones who specialize at one end, and the ones who specialize at the other, to have such disregard for each other. The great mass of workers in between, connecting one step to another, are improving all the time our understanding of… this tremendous world of interconnecting hierarchies.*

Richard Feynman, *The Character of Physical Law*