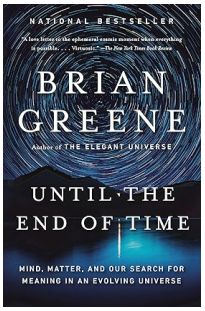
Until the end of time, mind, matter, and our search for meaning in an evolving universe *Brian Greene*. Alfred A. Knopf, 2020 (428 p.), isbn: 978-0525432173




Brian Greene

Brian Greene is a theoretical physicist and mathematician who has contributed to string theory. He became best known to a broader public though his popularizing books on cosmology. *The elegant universe* (1999, 2003) was his first of six at the time of writing this review. It won a prize of the Royal Society and was short listed for the Pulitzer Prize. It turned Greene into a media hype. New books appeared regularly, several were adapted to a documentary series for television: *The fabric of the cosmos* (2004) has a similar content reflecting on space, time and reality, and in *The hidden reality* (2011) he explores the multiverse aspect. In a photo book *Icarus at the Edge of Time* (2008) with pictures made by the Hubble telescope, he tells a short SF story for children about a boy approaching a black hole based on the Icarus myth, and *Light falls* (2016) is an audio book and a film about Einstein discovering the general relativity. The latter two can be found on YouTube. So he can be classified among the "superstars" of science, very present in the media.

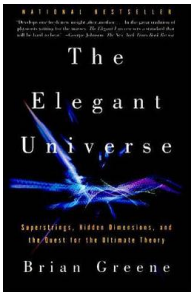
The elegant universe is an introduction to Einstein's space-time and general relativity, particle physics and quantum theory, and (super)string theory. The latter was the subject of his PhD. Around 2000, string and M-theory was the new hope for a generalized unified theory in the 21st century. Not everybody believed that. For example, Peter Woit was opposing the theory in his book *Not even wrong* (2007), and he even declared string theory dead in an interview of 2023.

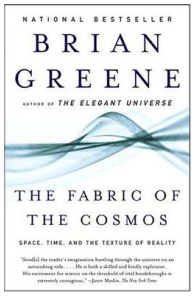
In *Until the end of time* Greene goes well beyond the cosmological story of the universe. The basic approach is still the physics of particles that with their energy, mass, and all the forces by which they interact (gravity, electromagnetic, strong and weak interaction), and in particular the role of, what he calls, the entropy two-step. If entropy is constantly increasing, how can something non-chaotic, such as life for example, come into existence?

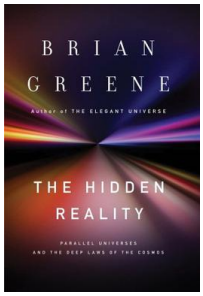
To explain this, he starts from the working of a steam engine. The energy packed in the fuel will heat the water, causing vibrating particles, increasing the entropy, which results in steam expansion, moving the piston, but which also results in cooling down and reducing the entropy, but also the intended motion of the piston which is a non-chaotic low-entropy result. However, there is also some waist in the form of heat that will increase the entropy of the environment. Thus low entropy energy captured in the fuel is transformed in low entropy energy of the motion and some high entropy energy in the form of waisted heat, lost in the environment. In this process entropy is moved from here to there, i.e., entropy flows, and since entropy measures information, there is a corresponding flow of information. Now processing of information can be used as a definition of thinking, and thus the same physical laws for the steam engine apply also to thinking. This principle of flowing entropy and information, says Greene, can also be applied to a biological situation. A living organism, is fuelled by food or energy from the sun, to produce structured, lower entropy forms of energy, for example its own continuation as a living entity, but at the same time it produces high entropy waist. This waist is the reason why a perpetuum mobile is impossible and why overall entropy is increasing and hence why time is essentially unidirectional.

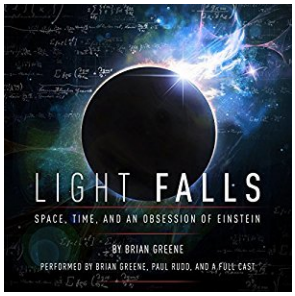
Another returning element in Greene's argumentation is Darwinian evolution. This makes biological systems more efficient in surviving, i.e., in producing low entropy structures but that will always be with an ever increasing amount of waist, increasing the entropy of the environment. As time goes by, some low probability transition will happen, and then Darwinian evolution will take over, filtering out the "fittest" elements to develop further. In subsequent chapters, Greene applies these arguments, first to explain why life came about in a soup of particles that clumped together forming atoms in an cooling plasma after the big bang and as inflation is followed by expansion,

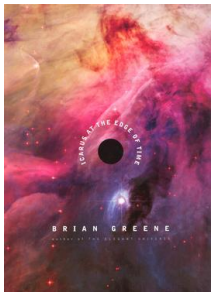
they clump even more to form massive stars and galaxies, and as circumstances allow forming the molecules that give rise to life. Life just happened accidentally because the circumstances were there. It could as well have been some other life form if circumstances would have been different.











The amazing fact is that all this follows from the mathematics that solve the equations describing all the physics of just an enormous amount of particles. But Greene does not stop there. Once there is some life form, Darwinian evolution takes over. What then eventually made us, humans, so successful? In successive chapters he describes the possible triggers that made us conscious, i.e., the origin of our mind, what made us aware of our existence and realize that we shall die some day. Next topic is an exploration of how and why we developed (spoken) language. There are of course no remaining fossils, so explanations are speculative. Why we tell stories, and use our imagination to create them. This is a step towards the urge to explain our origin, triggering different religions and beliefs to explain the observations that are not explainable by known scientific arguments. How did our brains develop instinct? Why did cavemen drow pictures on the wall? Why did the creativity of humankind produce many different forms of art? Greene discusses all of these questions. He starts with the Big Bang and closes the circle at the end towards the end of times. Is there a creator or designer that orchestrated this whole evolution described so far? What happens after we die? Is there some some timeless existence of our soul? Can all the information built up since the start be stored somewhere? Greene sketches the different possibilities based on the physics which predict several possible endings. The universe as we know it will certainly end, and if the information is kept alive by some entity which Greene calls the Thinker, then this entity will be forced by the physics to think slower and slower until time will stop because the particles will be distributed without interaction in an immense dark and cold universe which brings entropy to its completion. But Greene leaves a spark of hope because it is not impossible that there is some transition to a restart so that our mind will persist elsewhere, whatever that may be. Our hope is that one day we shall develop the mathematics that now describe the world from quarks to the cosmos but that will also provide answers to all the questions asked before that are still open for speculation or where only different possibilities can be conjectured.









Thus the chapters are linked as follows: creation of particles → time and entropy → information and life → mind → language and stories → belief and religion → creativity and arts → permanent (ending?) of the opera of the cosmos. This is an interesting read clearly exposing the enormous erudition of the author, but with arguments that often rely on conjectures or even debatable assumptions. It certainly makes you think, for example about Greene's explanation of what our free will comes down to. What can theoretical physics and all the mathematics on which it relies really explain, and how much can not yet be explained is a humbling question to ask and worth contemplating.

Adhemar Bultheel