Chapter 6

What Size is the Universe?
The Cosmic Uroboros

The size of a human being is at the center of all the possible sizes in the universe. This amazing assertion challenges not only the centuries-old philosophical assumption that humans are insignificantly small compared to the vastness of the universe but also the logical assumption that there is no such thing as a central size. Both assumptions are false, but we have to reconsider the key words of the assertion – center, possible, size, and universe – to reveal the prejudices built into them that constrict and distort our picture of reality. In the modern universe there is a largest and a smallest size, and therefore a middle size. The size of a thing is not arbitrary but crucial to its nature, which is why scale models can never really work. Only by understanding size and its role in determining which laws of physics matter on different size scales can we can get an accurate perspective on anything outside the narrow realm of human experience. This chapter will develop a new symbolic picture of the universe that portrays us in our true place among everything else that exists.

There are wildly different-sized objects in the universe. Betelgeuse is the bright star at the upper left corner of the familiar winter constellation Orion. It is a red giant so monstrously larger than our sun that it could fill the orbit of Mars. Earth is a mere pebble beside it. But compared to our home Galaxy, the Milky Way, Betelgeuse is just a spark in a raging forest fire. Clearly, these sizes are relative, and we need a language in which to discuss them without falling back on vague words like "huge," "tiny," or the most misleading of all, "infinite." (Just because a size is too big to grasp does not mean it is literally boundless.) The concept of "size scale" is a mental framework with which to define a chunk of reality. It describes our range of conscious focus at any given moment. *A size scale is not a physical entity but a setting of the intellectual zoom lens.* The size scale of an object is a region large enough to include the entire object but not so large that the object becomes insignificant.

Even if you don't like math, you can still easily compare $10 and $10,000. Comparison and manipulation of numbers are such different activities that they are performed in opposite hemispheres of the brain.[1] You think differently about buying something if it costs $10 than if it costs $10,000. In this case, the numbers are not something you have to manipulate; instead they define a certain general category. Price alone does not tell you everything. Is one thousand dollars a lot? Well, it is for a dinner but not for a car. So as with prices, the number that defines a size doesn't tell you whether something is "big" or "small." It only helps you compare it to something else. Unlike prices, which are usually expressed to the dollar or even penny, the numbers we use are mostly not intended to be precise but instead to suggest general ranges of size. Size scale is an approximate concept, but for the universe that is all we need.

The basic length unit we use is the centimeter, which is a little less than half an inch. There are 100 centimeters in a meter. The height of most people is between 1 and 2 meters (that is, between about 3 feet 3 inches and 6 feet 7 inches). This chapter is not going to pay any attention to size *differences* this small – one meter is the same as two meters for our purposes. Since the number 100 is written exponentially as 10^2, the height of people is in the 10^2 cm range. The raised exponent refers to the number of zeros after the 1. Mountains, the height of which is measured in kilometers (thousands of meters) are in the 10^5 cm range (100,000 cm). In the direction of decreasing size, a typical cell in your body is in the 10^{-4} cm range (0.0001 cm). Negative exponents tell you in which place after the decimal point the first non-zero digit occurs. The ratio between 10^2 and 10^3, or between 10^{-6} and 10^{-5}, is a factor of 10, and this is called one "order of magnitude." If we want to describe the difference between the size of a human being (10^2 cm) and the size of a cell (10^{-4} cm), we can say that they differ by 6 orders of magnitude. A human differs in height from a mountain by only 3 orders of magnitude (10^2 compared to 10^5 cm). Thinking exponentially, a human being is far closer in height to Mt. Everest than to a single cell, even though "common sense" leads many people to assume the opposite because they have no experience of how small a cell really is. Orders of magnitude may sound complicated at first, but as we use them they will begin to seem an essential part of language.

There is a Largest and Smallest Size

The powers of ten go on infinitely in both directions in pure mathematics, but not in the physical world. The smallest size exists because of the interplay between general relativity and quantum mechanics. We have already mentioned that relativity redefines space and time as spacetime; now we come to something it says about space and gravity. General relativity tells us that there can't be more than a certain amount of mass squeezed into a region of any given size. If more mass is packed in than the region can hold, gravity there becomes so intense that the region itself – the space – collapses to no size at all. This is a black hole. Nothing can escape from inside a black hole, not even light; hence the term. Any object compressed enough will hit this limit and suddenly become a black hole.[2]

Meanwhile, quantum mechanics sets the minimum size limit, but in a very peculiar way. Electrons, protons, and other particles have extremely small masses and are always whizzing about. They are very hard to pinpoint. The "size" of a particle is actually the size of the region in which you can confidently locate it. The smaller the region in which the particle is confined, the more energy it takes to find it, and more energy is equivalent to larger mass. There turns out to be a special, very small size where the *maximum* mass that relativity allows to be crammed in without the region collapsing into a black hole is also the *minimum* mass that quantum mechanics allows to be confined in so tiny a region. That size, about 10^{-33} cm, is called the Planck length, and it's the smallest possible size. We have no way to talk or even think about anything smaller in our current understanding of physics.[3]

The largest size we can see is about 10^{28} cm, which is the distance to our cosmic horizon. From the Planck length to the cosmic horizon is about 60 orders of magnitude. The number 10^{60} is extremely big, but it's not infinite. It's comprehensible. With it, we can begin to define our cosmic context.

Size Matters: The Key to Cosmic Perspective

The ancient Egyptian god Nun, the great unknowable and indescribable source of all the other gods, was sometimes portrayed associated with a serpent or even as a serpent. There is something about the image of a serpent that has led many cultures to associate it symbolically with the creation of the world and the unity of all things, especially when the serpent is represented as swallowing its own tail. In ordinary speech the word "serpent" is sometimes used interchangeably with "snake," but a snake is an animal, while a serpent is the symbolic, mythic, sometimes dreamlike representation of that animal. Snakes do not actually swallow their tails, but serpents can do anything humans can imagine. Adapting an idea of Sheldon Glashow, 1979 Nobel laureate in physics, we turn to the multi-thousand year-old symbol of the serpent swallowing its tail and give it a modern interpretation.[4] "Uroboros" is the ancient Greek word for a serpent swallowing its tail. We will call the symbol below the "Cosmic Uroboros." The tip of the cosmic serpent's tail represents the smallest possible size scale, the Planck length, and its head represents the largest size scale, the size of the cosmic horizon.

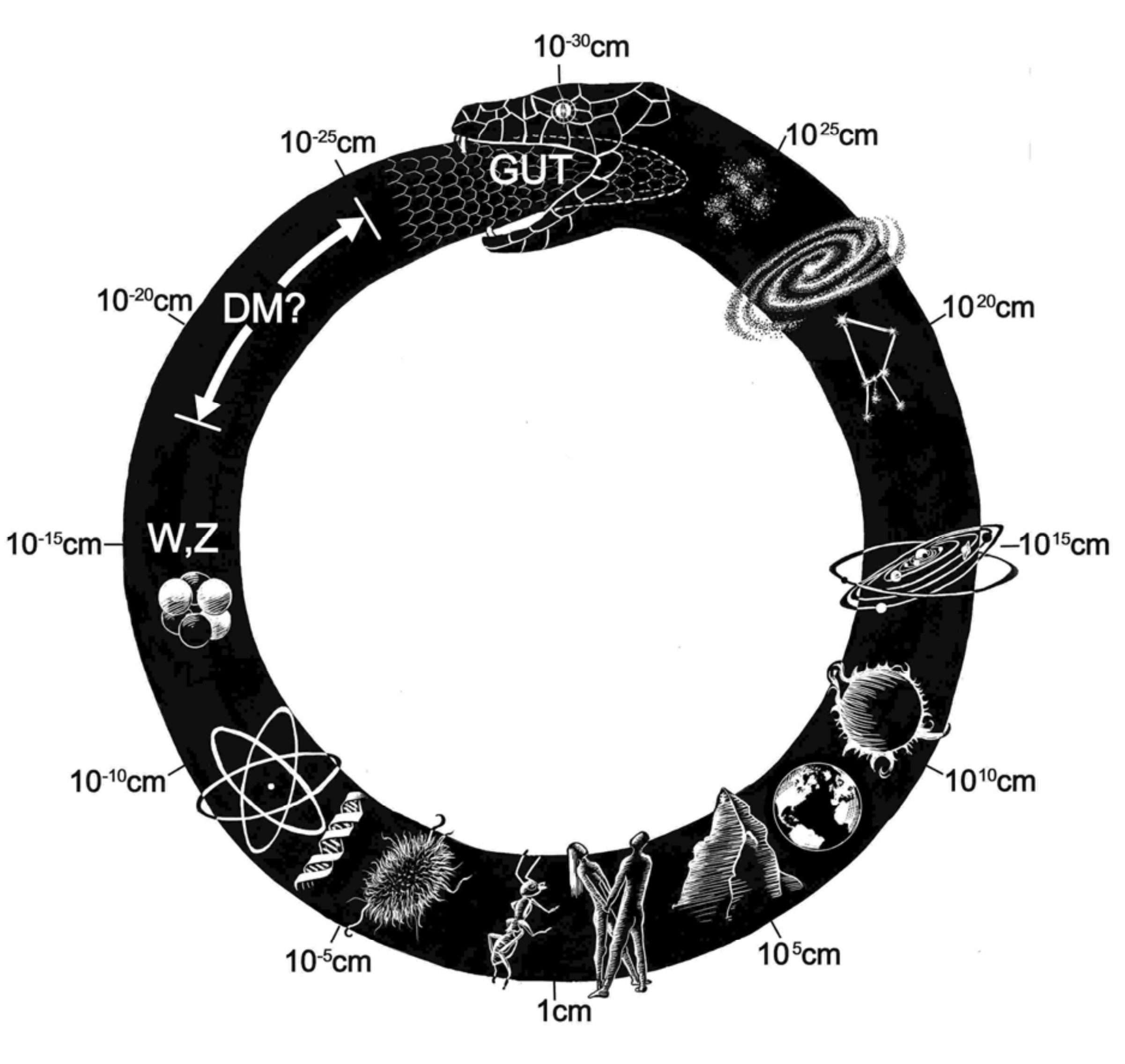

Figure 1. The Cosmic Uroboros represents the universe as a continuity of vastly different size scales. As Figure 3 of Chapter 4 shows, the diameter of the earth is about two orders of magnitude (10^{-2}) smaller than that of the sun. About sixty orders of magnitude separate the very smallest from the very largest size. Traveling clockwise around the serpent from head to tail, we move from the maximum scale we can see, the size of the cosmic horizon (10^{28} cm), down to that of a supercluster of galaxies, down to a single galaxy, to the distance from Earth to the Great Nebula in Orion, to the solar system, to the sun, the earth, a mountain, humans, an ant, a single-celled creature such as the E. coli bacterium, a strand of DNA, an atom, a nucleus, the scale of the weak interactions (carried by the W and Z particles), and approaching the tail the extremely small size scales on which physicists hope to find massive dark matter (DM) particles, and on even smaller scales a Grand Unified Theory (GUT) . The tip of the tail represents the smallest possible scale, the Planck length. Human beings are just about at the center.

Let’s get oriented on the Cosmic Uroboros. Most of the time we humans are conscious only of things from about the size of ants to the size of mountains. This range of sizes corresponds to the bottom of the Cosmic Uroboros – if it were a clockface, it would fall approximately between 5 o’clock and 6:30, just about the middle. This is humanity’s native region of the universe, our true homeland. This is the “reality” in which common sense works and normal physical intuition is reliable. It’s not a geographical location: it’s a point of view. We will name this range of size scales “Midgard,” a name for Earth borrowed from the Norse creation myth, the Edda, in which the world of human beings was seen as midway between the land of the giants and the land of the gods.[5] For much the same reason, the ancient Romans named their sea the Mediterranean, literally “middle of the earth.” We have chosen the name Midgard for our human-scale homeland in the modern universe not because it is between heaven and hell or any other spiritual dualities, but because it is midway between the largest and smallest sizes. This turns out to be the only size that conscious beings like us could be. Smaller creatures would not have enough atoms to be sufficiently complex, while larger ones would suffer from slow communication – which would mean that they would effectively be communities rather than individuals, like groups of communicating people, or supercomputers made up of many smaller processors.

Different physical forces control events on different size scales. Electrical and magnetic (electromagnetic) forces control what happens from atoms up to mountains, even though gravity also plays a role. But around the size scale of mountains, gravity starts to gain the upper hand. The maximum size of mountains is determined by a competition between electromagnetism and gravity. The electromagnetic force is the glue of the chemical bonds that hold together the atoms that mountains are made of, and the strength of the glue is the same everywhere, regardless of the size of the planet. But the strength of the gravitational force grows with the increasing mass of the planet or of the mountain. When the mountain becomes big enough, its gravity overcomes the electromagnetic forces that hold mountains together, and the roots of the mountain flow or break, causing earthquakes. The smaller the mass of the planet, the weaker the gravity pulling the mountain down. Consequently, mountains can be much higher on smaller planets like Mars than they are on Earth.[6] Since the strength of gravity continues to grow with mass, once we reach that part of the Cosmic Uroboros where gravity controls, all larger scales are also controlled by it and all other forces become less important.

Moving counterclockwise from Midgard up into the larger size scales means adjusting our conscious focus, zooming out to encompass vaster regions, where gravity has counteracted the headlong expansion of the universe by collecting matter in those regions that in the early universe happened to be slightly denser than average. Gravity eventually stopped the cosmic expansion in those regions, and gravity has ever afterward shaped and held everything in the region together in a beautiful, dynamic, yet stable structure – a galaxy, in which stars and planets formed and evolution has had time to work its wonders. The largest structures astronomers see are the great sheets of galaxies known as superclusters. In the old Newtonian view, there was no known object larger than a star, and stars were randomly distributed forever. But in the new cosmology not only are there galaxies, each containing hundreds of billions of stars, but there are superclusters of tens of thousands of galaxies, which astronomers have been mapping since the mid 1980's. That, however, appears to be the end of the line. We see no structures larger than superclusters. On scales much bigger than superclusters, the universe becomes increasingly smooth. If each supercluster were a dot, the visible universe would look much the way Newton expected. He was right about the universe being essentially uniform, but on the wrong scale: he thought the *stars* were scattered more or less evenly, but instead it's the superclusters.

Moving clockwise now on the Cosmic Uroboros, zooming way inward past Midgard to the very small, we reach the size scales of subatomic particles. This is the region controlled by what are called the strong and weak interactions. These forces are active only on scales smaller than atoms.[7] Gravity is of no importance at all on these scales. In fact, gravity's power fades out at the small end of Midgard. It can't hurt a mouse. You can drop a mouse down a thousand-yard mine shaft and at the bottom, as long as the ground is soft, it will walk away.[8] Gravity plays virtually no role in the life of bacteria, which are at about 7 o'clock on the Cosmic Uroboros. From there until about 12 o'clock, gravity is completely irrelevant.

But then a strange thing happens. As we continue along the Cosmic Uroboros to the very tip of the tail, gravity becomes extremely powerful again. The reason is that gravity's strength increases as objects get closer to each other, and at the tip of the tail distances between particles are almost unimaginably small. The Cosmic Serpent swallowing its tail represents the possibility that gravity links the largest and the smallest sizes and thereby unifies the universe. This actually happens in superstring theory, a mathematically beautiful idea which is our best hope for a theory that could unify quantum theory and relativity. In string theory, sizes smaller than the Planck length get remapped into sizes larger than the Planck length.[9]

The latest breakthrough in particle physics was the realization in the 1960s and 1970s that the strong and weak forces are closely related to the electromagnetic force. In the very successful "standard model" of particle physics based on this, elementary particles are treated as if they are points with certain properties. But the standard model cannot be the final word on the subject, since it cannot explain why, for example, electrons and other elementary particles have the masses and other properties that they do. So physicists have been trying for several decades to go beyond the standard model. The very speculative but promising physics of string theory suggests that not just electrons but all elementary particles might just be the ways a single kind of tiny looped string can vibrate, and in that case an electron would be just a *way* a string vibrates. An identical string vibrating in a different way would be a different particle. Just as only certain shapes of electron clouds are allowed in atoms, only certain sorts of vibration (and thus of particles) are possible. An electron is a special sort of vibration: it is the lowest mass vibration having the property of electric charge. String theory has striking mathematical elegance: it might even be true, and it's so powerful that it might eventually allow physicists to understand the reason for quantities like the masses of elementary particles. However, string theory only works if you assume a world with ten dimensions – one time and nine space dimensions. No one has figured out what string theory implies for the world of one time and three space dimensions that we actually experience – not only with our senses but with our most sensitive scientific instruments. Consequently, this beautiful theory has not made a single testable prediction yet (except possibly for the existence of supersymmetric particles like the WIMP dark matter particle), so we don't yet know how to evaluate its claim that particles are "really" vibrating superstrings.

There is a second meaning to tail-swallowing that may seem strange at first. Swallowing may have existed *before* the serpent. At the beginning of the Big Bang, if our present understanding of the laws of physics is right, there was nothing but the head of the Cosmic Uroboros with the tip of the tail in its mouth. There was little of the body because there was little difference between the smallest scale and the largest scale. The smallest scale is fixed by the constants of nature, and the largest scale, the size of the cosmic horizon, was only a little larger than that because the universe was so young and had not yet had time to expand. The body filled in later as the universe expanded and evolved. Thus tail-swallowing may express a fundamental aspect of the evolution of an expanding universe.

The Cosmic Uroboros represents not only a way to structure the universe but also a dream that has been an underlying personal motivation for many scientists. "What I'm really interested in," Einstein said, "is whether God could have made the world in a different way; that is, whether the necessity of logical simplicity leaves any freedom at all." [10] This question is still open. The universe could possibly have been organized in many ways and just happened to end up the way we find it. But it is also possible that there was only one way everything could have worked together. The dream of physicists is to find the theory that answers such questions and ties everything together – a "theory of everything." The Cosmic Uroboros swallowing its tail thus symbolizes the dream of a theory of everything, which will tie together our understanding of the universe. Through this dream, physicists are expressing a desire perhaps even more ancient than the uroboros symbol: to feel coherent and at home in the wholeness – to experience reality as One.

Even if there is no success in that quest for years to come, the Cosmic Uroboros can help us right now to appreciate our extraordinary place in Midgard. The centrality of Midgard on the Cosmic Uroboros has nothing to do with the units we choose to measure length. Whether measured in centimeters or light years, Midgard would always fall in the middle. Midgard, as we have said, is not a special location in space – it is a special size scale, and it is *everywhere* in the universe.

As a serpent, the Cosmic Uroboros is much more than a circle, because every point on it is unique. There is a head and a tail, and therefore every point in between has a relative position. There is a beginning and an end, even though they overlap and are interdependent and inseparable. On a circle, all points are identical. On the Cosmic Uroboros every point has its own meaning. The uroboros has been used to represent the continuity of whatever universe a tribe or people perceived themselves to be living in. Something about the serpent swallowing its tail has resonated in the human imagination for thousands of years. We humans are not yet able to explain the perennial attraction of this symbol, and it may be deeper than our conscious understanding. The serpent's exceedingly simple and flexible body has been endlessly twisted and artistically embellished. It has been seen as both goddess-like and evil, fascinating and repulsive, finite and infinite, yin and yang. [11] None of this rich history would have been implicit in a circle. The uroboros symbol as we interpret it here is capable of representing the modern universe at least as completely as it represented the universes our ancestors imagined. The Cosmic Uroboros resurrects an ancient symbol whose possibilities are by no means exhausted.

Why Scale Models Never Work

Galileo was probably the first to understand the physics of size scales and to realize that size is not arbitrary but crucial to the nature of each thing, determining both its shape and its function. In his 1638 book *Discourses Concerning Two New Sciences* (in which he invented the fields we would call today "mechanics" and "strength of materials"), he explained with simple arithmetic why large animals cannot look like small ones.

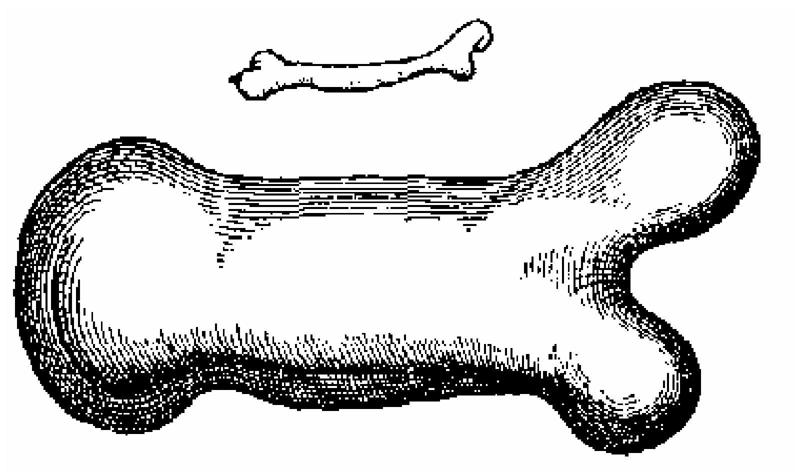

Figure 2. Galileo's bones: his own drawing illustrating scale model failure.[12]

At the top is the delicate bone of an animal, and below it is the bone as it would have to be if the animal were three times taller or longer. The reason the second bone would be so much bulkier, Galileo figured out, is that the strength of bones is determined by the area of their cross-section. Area is a two-dimensional quantity (length × width). If you make the bone three times as long, always keeping it the same shape, the area of its cross-section goes up nine times, but the weight is three-dimensional and goes up 3×3×3 or 27 times. The animal's new weight would crush its bones. This is why an elephant does not look like a large gazelle.

With this simple calculation Galileo ruled out entire classes of what prescientific people had always considered natural possibilities – like elves and giants. He did it by thinking through what would happen if you scaled up only 3 times. But from the smallest scale to the cosmic horizon is 10^{60}! There is absolutely no way that unaided human intuition can predict or even imagine how things work on such distant scales. *Physical laws that apply at one scale do not cease to be true at other scales: they merely cease to matter*. Conversely, laws whose effects were nonexistent at one scale become overwhelmingly important on another, and reasoning that is valid on one scale may not work on another.[13] Atoms are the same size everywhere in the universe, a size that is set by fundamental quantities such as the masses of the elementary particles and the strengths of their interactions. The properties of materials are very different on small size scales – closer to the dimensions of atoms – than they are on larger scales. The smallest living creatures have to be large enough to contain a huge number of atoms in order to have sufficient chemical complexity to do the things that living things do – such as using energy to process material and to reproduce.

Scaling ideas are very broadly useful, from understanding the possible forms of life on other worlds to understanding politics on our own, since what works for a family may not work for a town, and what works for a country may not work for a world. We'll return to this later, but for now we are concerned with pointing out two classic problems that result from assuming that reasoning that works on the human scale must also work everywhere else.

Mental Muddle #1: Scale Confusion

There is no single physical phenomenon that occurs on all size scales. There are no galaxies the size of atoms. Different kinds of things happen on different size scales, and to talk about something in the context of a size scale in which it cannot occur creates a mental muddle we call *Scale Confusion.* Scale Confusion is applying laws and understandings appropriate to one size scale to phenomena on another scale where those laws and understandings don't apply.

Consider water. Water comes in the forms of ice, liquid, or steam, but how little of each of these things can you have? Can you have a single molecule of ice, or liquid, or steam? No. A water molecule is just H_2O – two hydrogen atoms and an oxygen atom. Ice, liquid, and steam are all meaningless concepts on the scale of a single water molecule. It takes millions of water molecules to make the smallest snowflake. "A molecule of ice" would be an oxymoron because it involves Scale Confusion. If ice, liquid, and steam are actually qualitatively different, and they don't exist in a single molecule of water, where do they come from? Can they be latent in the water molecule? The way a water molecule interacts with others of its kind may be characteristic of the molecule. But entirely new phenomena, such as "phase transitions" between liquid water and ice, become possible only on a larger scale involving vast numbers of molecules. *Complexity itself generates new kinds of behavior every few powers of ten, all around the Cosmic Uroboros*. This is analogous to the change in perspective between a child of 5 and an adult of 25, and between adults of 25 and 75 – a maturing perspective does not mean more of the same: perspective eventually changes qualitatively as it changes quantitatively.

As another example, the second law of thermodynamics describes the tendency toward increasing disorder, or "entropy." If you leave a bottle of perfume open, the perfume will evaporate. The molecules, so nicely ordered in their compact container, will float off randomly in the room, increasing the entropy. They will never come together by chance and reunite inside the bottle – entropy doesn't spontaneously decrease. We can't easily recognize increasing disorder in very simple systems. If someone runs a movie of two billiard balls hitting each other and bouncing away, there is no way to tell if the movie is being run forward or backward. But if you see a movie in which 15 scattered balls suddenly come together to arrange themselves in a perfect triangle and the cue ball comes flying off, you can be certain the movie is running backwards. Although entropy is irrelevant with 2 or even 3 balls, with 16 balls entropy is already a clearly observable property of the system. Entropy is called an "emergent property" because it only emerges when a system becomes sufficiently complex.

The idea of emergent properties is becoming well known, and many examples have been described in different fields.[14] Consciousness may itself be an emergent phenomenon. Roger W. Sperry, the 1981 Nobel Prize winner in medicine who discovered the functions of the left and right hemispheres of the brain, wrote that contrary to the traditional thinking in consciousness research, consciousness was in his view not reducible to physical and chemical processes. Beliefs and values are what control conscious behavior, not the underlying brain processes that have traditionally been thought to be fundamental. Consciousness, he concluded, is an "emergent property" that does not exist at a lower level of complexity.[15]

Although we can't say what consciousness is, we may be able to say what it is not. In the late 19th and early 20th centuries in Russia there was a philosophical movement called "Cosmism" which was especially popular among scientists.[16] The Cosmists believed the universe was filled with intelligent aliens, and in preparation for humans perfecting themselves and establishing utopias in space, Cosmists like Konstantin Tsiolkovsky laid the technical foundations for much of rocketry, orbiting space stations, and space colonization. But their movement went beyond science. They believed that consciousness exists in every particle in the universe, including every star and galaxy, and that humans and intelligent aliens have the highest concentration of this consciousness and therefore the greatest responsibility to further the peaceful development of still higher consciousness. The Cosmists had many ideas that are still worth developing, but we don't believe that this view of consciousness is one of them. Consciousness can only exist at those high peaks of concentrated stardust where life and intelligence can evolve. It is a rare jewel in the cosmos.

There are many individual examples of emergent phenomena, but considering them one by one is like reading notes for an unwritten book on scraps of paper thrown into a shoebox. The Cosmic Uroboros provides a *structure* that makes sense of the notes, fills in the gaps, and tells a story. Along the cosmic serpent new properties emerge with each sufficiently large change of scale, and new laws dominate at new levels of complexity. The whole is incomparably greater than the sum of its parts.

Here is perhaps the most complicated (and controversial) instance of Scale Confusion: the question, "Does God exist?" The Scale Confusion inherent here (we will ignore the difficulty of defining God) is that "existence" is actually a property of the middle of the Cosmic Uroboros. It is not a word that means the same thing at different size scales. On a small scale, do electrons exist? The electron is a very useful concept – a particle with specific properties that we can talk about – but there is no solid thing, only a "probability cloud." In other words, the probability of its being somewhere is what's real. It doesn't make sense to say electrons exist in the commonly understood meaning of the word. But it makes even less sense to say they don't exist, because when you flick the switch, electricity flows and lights turn on. The confusion is due to the fact that when speaking of elementary particles, we lack any intuitive sense of their strange state, and "existence" is at best a metaphor. Niels Bohr, one of the founders of quantum theory, made this point, saying, "When it comes to atoms, language can only be used as in poetry. The poet, too, is not nearly so concerned with describing facts as with creating images."[17]

In the same way, very large scale things can only metaphorically be said to "exist." For example, look in the direction of the constellation Virgo (a pattern of nearby stars) but look through it – look much, much farther away. There lies something astronomers have labeled the "Virgo cluster of galaxies." Certainly it is simpler to ask whether a galaxy cluster exists than to ask whether God exists, so let's ask the question: do galaxy clusters exist? Since we see each galaxy in a cluster at a different time in its history, due to the finite speed of the light coming to us from it, the cluster as we see it is a construction of our thought. Even the constellations Orion or the Big Dipper, which are made entirely of nearby stars inside our own Galaxy, don't really exist, since if we looked at those stars from a different vantage point, the pattern would be entirely different. The appearance of the Big Dipper is not even stable from the vantage point of the earth but is slowly changing as the stars that make it up move in their separate ways around the center of our Galaxy. The truth is that as we move further and further away from the human scale toward either larger or smaller scales along the Cosmic Uroboros, the concept of "existence" becomes increasingly metaphorical. "Existence" is a clear property only in the middle of the Cosmic Uroboros, our solid, reassuring, comforting homeland of Midgard. Unless God is by definition confined well within these limits, God can't be said to exist – or not to exist.

Mental Muddle #2: Scale Chauvinism

We propose the name Scale Chauvinism for the natural assumption that the way things look on some particular size scale is fundamental, and everything else can more profitably be viewed from this fundamental point of view. The most common chauvinism, of course, is chauvinism of the human scale. As Protagoras said, according to Plato's *Theaetetus*, "Man is the measure of all things." But human-scale chauvinism isn't the only possible kind. Richard Dawkins has written a fascinating book called *The Selfish Gene* in which he argues that living creatures such as human beings are actually DNA's method of propagating itself.[18] Humans exist for the sake of the DNA, which is, in Dawkins' terms, "God's Utility Function" – that is, in this metaphor from economics, DNA is the good that God tries to maximize. In Dawkins' view, the molecular level is fundamental. In a different mindset, James Lovelock argues that planet earth may be a self-regulating organism that he calls Gaia, after the ancient Greek goddess of earth.[19] According to Lovelock's "Gaia Hypothesis," what individual plants and other organisms are doing is not understandable if considered only from the point of view of survival of the organism itself. The behavior of plant and animal populations is best understood as being part of Gaia's constant adjusting of its temperature and atmospheric constituents to maintain homeostasis, or stability. Lovelock regards the global scale as fundamental with smaller size scales serving the goal of the health of Gaia herself, life itself. Both these theories are wonderfully eye-opening – *if* they are understood as potentially useful approaches to the many faces of the universe. Many size scales hold critically important perspectives on reality. But none is more fundamental than the others. They all have a place on the Cosmic Uroboros.

A particularly dangerous form of Scale Chauvinism is the kind of thinking called "radical reductionism." This is not the same as "reductionism," which in science is the perfectly reasonable idea that explanations of large-scale phenomena must be *consistent with* scientific knowledge about smaller scales.[20] "Radical reductionism" – which is usually what people mean when they criticize "reductionism" – is the argument that larger scales can be *explained* by knowing what is going on at smaller scales. This is the "nothing but" argument: politics is nothing but psychology, psychology is nothing but biology, biology is nothing but chemistry, and chemistry is nothing but physics. To the radical reductionist, the Cosmic Serpent does not swallow its tail – there is no serpent. All that "really exists" is the tip of the tail. Everything always "boils down" to physics. But it is difficult to find even a single example where such thinking has led to deeper insight, let alone scientifically useful predictions.[21] Larger scales don't boil down to smaller ones. To the contrary, scientific laws and organizational principles that were irrelevant on small scales come into play on larger scales. Subatomic, human, galactic – the universe unfolds fully on all scales, and all are fundamental even though human consciousness can usually only focus on one scale at a time. The essence of Scale Chauvinism is failing to use the zoom lens. The essence of Scale Confusion is arbitrarily sliding the zoom lens and not realizing that this has consequences. The key to seeing the universe in clear focus is to learn to operate the zoom lens and to respect the uniqueness of every size scale.

Are We Insignificant?

Many people today contemplate the stars and the vast distances in between and conclude how insignificantly small we are compared to the universe. This view has contributed to a sense of alienation and sometimes even despair that have for more than three centuries been a reaction to humanity's demotion from the pinnacle of God's creation to a tiny speck floating in endless space. But now we understand something we didn't know before.

There is no thing and no force in the universe that is significant on all size scales. Gravity is certainly a significant force in the universe. On the grand scales of galaxies and clusters of galaxies, the motion of all matter is controlled by gravity. In the headlong expansion of the universe, the only thing that pulls matter together and maintains it in rare oases of stability is gravity. Only gravity's absolute stability could hold together a solar system and give evolution the time to create, by the interplay of pure chance and natural selection, levels of complexity like intelligent life. Gravity may even be the key to the Cosmic Serpent swallowing its tail. How could anything be more significant than gravity? But gravity plays no role whatsoever in the attraction between magnets or people, or, as we said earlier, in the lives of very small creatures. Similarly, the "strong force" is overwhelmingly powerful inside the atomic nucleus, but it falls off quickly with distance and outside the nucleus it is quite insignificant. If the forces of nature themselves are insignificant on some scales, humans are doubtless also insignificant on some scales, although not on our own. *Everything in the universe is significant on some scales, insignificant on others.* All human knowledge could be stored in something the size of a computer chip. If it were, would its smallness make it insignificant? Living on the Cosmic Uroboros, absolute size has nothing to do with significance.

The Meaning of Midgard

Intelligent creatures in the universe have to be midsized. There is a kind of Goldilocks Principle: creatures much smaller than we are could not have sufficient complexity for our kind of intelligence, because they would not be made of a large enough number of atoms. But intelligent creatures could not be much larger than we are either, because the speed of nerve impulses – and ultimately the speed of light – becomes a serious internal limitation. We are just the right size. You might expect that a galaxy-scale intelligence would think at a fabulously deep level. But in fact the number of thoughts that could have traveled back and forth across the vast reaches of our Galaxy in its roughly 10 billion-year lifetime is perhaps the number an average person has every few minutes. The speed of light seems dizzyingly fast to us, but on the scale of the visible universe it is excruciatingly slow and would prevent the parts of any large intelligence from communicating with each other in a reasonable amount of time compared to the age of the universe. Thus the cosmos can't have a central brain or government. Thinking must be decentralized to make any progress, given the limit of the speed of light.

Real thinking is the job of our size scale – beings more or less our size, bigger than an ant, smaller than a mountain, beings of Midgard. We humans exist on the only size scale where great complexity on the one hand and immunity from relativistic effects (like the speed of light) on the other are both possible. Our consciousness is as natural a blossoming on this special scale as a star is on its size scale or an electron on its own.

Not only do intelligent creatures have to be approximately the size we are, but the universe had to be more or less the size and age it is to have produced us. Atoms formed as the universe expanded and cooled. Galaxies formed as gravity resisted the expansion of the universe in regions that were denser than average. The first generation of stars could not have had planetary systems supporting life. Those stars contained only the elements that emerged straight from the Big Bang. All the heavier elements came into existence by being manufactured over time inside stars. The most massive stars burst into supernovas at the ends of their brief lives, dispersing heavy elements into space. For us to have come into existence, some of those elements had to find their way across vast, empty space into star-forming regions of galaxies and be sucked in by gravity to become later-generation stars like our sun, together with their new planetary systems. This process and the subsequent evolution of intelligent life on our planet required many billions of years, during all of which time the universe was inexorably expanding. Thus we could not have evolved until the universe was about as big as it is now.[22]

The Cosmic Uroboros shows that no being occupies an isolated niche. Stars are not merely stars; some of them are the centers of planetary systems and sustain whatever life there may be. Dark matter is not merely a lot of individual invisible particles; collectively it shapes the galaxies and holds them together as they spin, and it shepherds thousands of galaxies into the largest-scale structures in the universe, the superclusters. Electrons, bacteria, humans, and galaxies are phenomena that occur on different size scales along the Cosmic Serpent, but all have effects on other scales than their own, sometimes even across the Cosmic Uroboros.[23] The way to think about the universe is not as actually being a certain way, but as one way from the perspective of one scale, and another way from the perspective of another. In the end all scales are unified by the universe itself, and thus the serpent swallows its tail. Our Galaxy is at the center of the Cosmic Spheres of Time because every galaxy is, but we are at the center of the Cosmic Uroboros by the interplay of the complexity of our brains and the age of the universe. In yet another sense that could never have been foreseen before modern cosmology, we truly are at the center of the universe.

In seeing themselves as central to the universe, our ancestors were right, but like Newton, they too were right on the wrong scale. They saw their own little population as central, when in fact all living beings of about our size are central. Their error was to define themselves far too narrowly, as most people still do. In Shakespeare's *Hamlet* when the traveling players visit the court of Denmark, Hamlet asks them "to hold, as 'twere, the mirror up to nature; to show virtue her own feature, scorn her own image, and the very age and body of the time his form and pressure."[24] In a sense this book too is trying to hold a mirror up to nature, to use art and image and symbolism, as every cosmology has done, to reflect what cannot be directly described, and in so doing to show the very age and body of the time that we mean something in the cosmic context. Modern cosmology presents a new perspective that can help us not only to appreciate the awesome completeness of the universe but also to find what it means to each of us to be the human part of it.

I do not see a delegation
For the four-footed.
I see no seat for the eagles.
We forget and we consider
Ourselves superior.
But we are after all
A mere part of the Creation.
And we stand somewhere between
The mountain and the ant.
Somewhere and only there
As part and parcel
Of the Creation.

Chief Oren Lyons, Onondaga Nation, Iroquois Confederacy[25]

Contemplating the Cosmic Uroboros

The Cosmic Uroboros has no beginning, because it is all here all the time. But to speak about it with words, we must start somewhere. So let's begin with that spot at the bottom that represents our own world, the world of things that are measured in meters or miles, the realm of Midgard.

In Midgard you – personally – are midway between the size of a living cell and the size of Earth. Think of a single cell on the tip of your finger. That cell is as tiny compared to you as you are compared to Planet Earth. A single atom in that cell is as tiny compared to you as you are compared to the sun.

Now imagine that you curl yourself up into a ball and you* become *that atom in the cell on your finger. What does the world look like? Your electron cloud touches the electron clouds of the atoms all around you. It is a cozy world.

But now imagine that you, much more tightly curled up, are the nucleus of that same atom. You look outward but it is six miles to the next nucleus of your kind, and there is little comfort in knowing that three miles away its electron cloud is touching yours.

Imagine now that you are a star. It is an even lonelier world. You are sitting here in California, and your closest neighbor is in Australia. You are the only two people on Earth. Even if you are a star in a globular cluster, that tightest of all star clusters, your closest neighbor is still a thousand miles away.

Imagine now that you are a galaxy. Things become almost cozy again. Other galaxies are not far away. In this room, your nearest neighboring galaxy is sitting only 20 feet from you. If you are in a rich cluster of galaxies, your nearest neighbor is only a few feet away, and you feel like a person at a cocktail party. But conversation is virtually impossible. For you to think a single thought takes many thousands of years, because you can't think faster than the speed of light. It takes 100,000 years for one thought to cross your mind, and many times that to formulate an idea. You have only had time for a few galactic ideas in the ten billion or so years that you have been forming. Thinking is the privilege of creatures who live in Midgard.

Now imagine that you are a supercluster of galaxies. You are touching the next supercluster, and it touches the next, like people holding hands and encircling large voids. But your consciousness is wavering and flickering because unlike a galaxy, you, the supercluster, are not really bound together by gravity. Your parts are expanding away from each other. In time you will drift apart like clouds in a blue sky. And yet whatever you are will last many billions of years.

The universe looks different and works differently on different size scales, but you can't tell that from looking around, because any size scale you focus on appears to be reality itself.

Now let your attention slide down the Cosmic Uroboros back to Midgard. This journey through other size scales was a gift of thought, something possessed only by the luckiest citizens of Midgard. All the channels of imagination that stream

throughout the universe start in Midgard, and they all return here. Midgard is the Eden of the universe.

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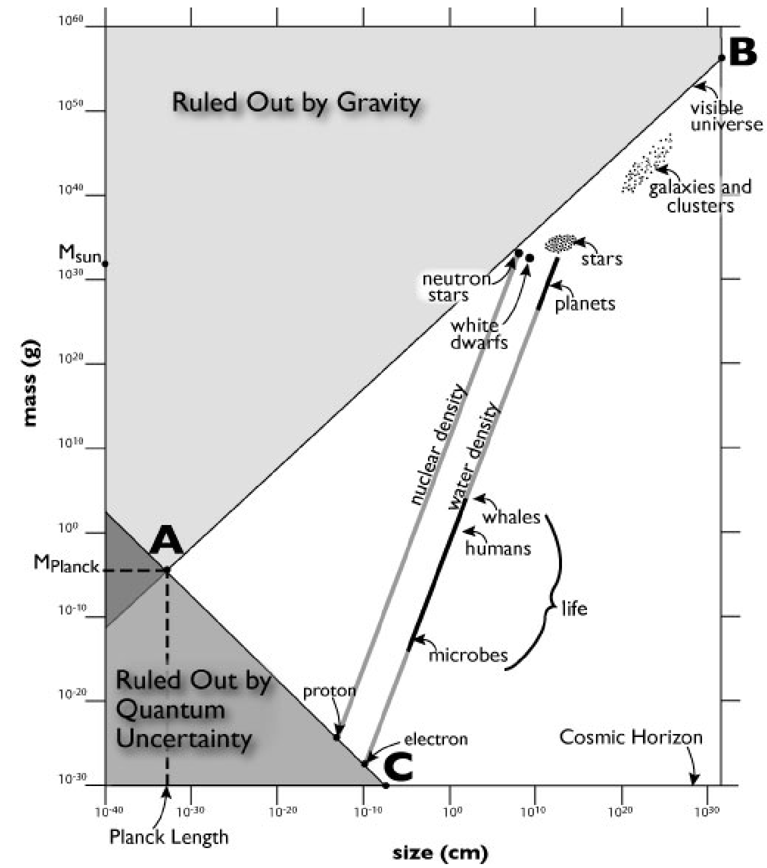
[1] "The left hemisphere is more associated with specific mathematical functions, while the right appears better equipped for comparing numbers." Andrew B. Newberg, Eugene G. D'Aquili, and Vince Rause, *Why God Won't Go Away* (Ballantine Books, 2001), p. 169.

[2] Astronomers have actually observed two kinds of black holes. One kind forms when giant stars reach the ends of their lives and become "core-collapse" supernovas with massive cores. These supernova-remnant black holes have masses a few times larger than that of the sun. The other kind of black holes are found at the centers of galaxies, and have much larger masses, as much as billions of times that of the sun. The masses of these "supermassive black holes" are observed to be tightly correlated with the properties of their host galaxies, and this shows that they are produced as part of the galaxy formation process.
Physicists don't actually know how objects smaller than stars can be compressed so much that they can become black holes. Stephen Hawking suggested that black holes with much smaller masses than stars might have formed during the Big Bang at the beginning of the universe, and he showed that such small-mass black holes would eventually evaporate by emitting "Hawking radiation." But such black holes have not been found and may not in fact exist.

[3] It takes more energy to localize an object in a smaller region. (For example, we have to look with shorter wavelength radiation, and the shorter the wavelength, the higher the frequency and therefore the greater the energy, according to quantum theory.) Mass is related to energy by Einstein's famous formula $E=mc^2$, so more energy means more mass. This leads to the counterintuitive result that as particles get smaller, they must get more massive, since it takes more energy to localize them. Thus an electron, which weighs only 1/2000th as much as a proton, is considered "bigger" than a proton in size (not mass) because it's harder to pinpoint. It does not occupy a fixed location but is within a cloud of that size. The Planck length is named after the physicist Max Planck, one of the inventors of quantum mechanics, who first calculated it. The Planck time (about 10^{-43} seconds) is the tiny amount of time it would take light to cross the Planck length. General relativity and quantum mechanics do not permit scales below the Planck limit. To observe a particle on the Planck scale, one would have to bombard it with an amount of energy equivalent to the Planck mass (about 2.2×10^{-5} grams), which would cause the region to collapse into a black hole, which would then evaporate in a Planck time. This is why it makes no sense to think of a region the Planck size as if it were ordinary space. A comprehensive theory of "quantum gravity," which would encompass and thus supersede both quantum mechanics and general relativity, is still a dream of physics. Superstring theory is our current best hope of such a theory.
These ideas are represented graphically in the plot below of size vs. mass. Our modern theory of gravity, Einstein's general relativity, rules out the upper region of the figure, above the line from A to B; any object in this region is a black hole of negligible size. Quantum uncertainty rules out the lower region, below the line from A to C. Thus all possible physical objects must lie in the wedge-shaped region where various representative objects are plotted. The point of the wedge A is at the Planck length. Note that the sloping lines on which most objects lie are lines of constant density, and that living organisms, planets, and normal stars like our sun all have approximately the same density as water, while neutron stars have the same density as atomic nuclei.



[4] Sheldon Glashow was one of the originators of the idea of a Grand Unified Theory that would combine the weak and electromagnetic interactions with the strong interaction. Glashow's first version of the cosmic Uroboros is reproduced in Tim Ferris, *New York Times Magazine,* Sept. 26, 1982, p. 38; see also Sheldon Glashow with Ben Bova, *Interactions* (Warner Books, 1988), Chapter 14.

[5] Old Norse *gard* meant earth, place, or home – in modern English, *yard***.**

[6] See Victor F. Weisskopf, *Science* **187**, 605 (1975), and John D. Barrow and Frank J. Tipler, *The Anthropic Cosmological Principle* (Oxford University Press, 1986), pp. 307-308.

[7] The nucleus of an atom is made of positively charged protons and uncharged (electrically neutral) neutrons, as we explained in Chapter 4. The strong force is what holds the nucleus together. It far overpowers the electrical force, which would on its own cause the protons to repel each other and fly apart. But the strong force has a short range that does not extend beyond the atomic nucleus. The weak force, which comes into play in many processes in which particles decay or are transformed into other particles, has an even shorter range.

[8] This example is from J. B. S. Haldane, *On Being the Right Size and Other Essays,* edited by John Maynard Smith (Oxford University Press, 1985). In his essay “On Being the Right Size” (originally published in 1928) Haldane goes on to explain that “a rat is killed; a man is broken; a horse splashes. For the resistance presented to movement by the air is proportional to the surface of the moving object. Divide an animal’s length, breadth, and height each by ten; its weight is reduced to a thousandth, but its surface only to a hundredth. So the resistance to falling in the case of the small animal is relatively ten times greater than the driving force.” For a critique, along the same lines, of the failure of creatures in science fiction films to obey scientific laws, see Michael LaBarbera, “The Strange Laboratory of Dr. LaBarbera,”

University of Chicago Magazine, October-December 1996 (http://magazine.uchicago.edu/9612/9612LaBarbera.html). The irrelevance of gravity to bacteria is explained by R. C. Lewontin, in *Hidden Histories of Science*, edited by Robert B. Silvers (New York Review of Books, 1995).

[9] This remapping, or duality, of string theory is explained in Chapter 10 of Brian Greene, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* (Norton, 1999), especially pp. 252-254.

[10] Einstein's remark to his assistant Ernst Straus, as quoted in Gerald Holton, *The Scientific Imagination: Case Studies* (Cambridge University Press, 1978), p. xii. Max Jammer, in *Einstein and Religion* (Princeton University Press, 1999), p. 124, gives the quotation in German from E. Straus, "Assistent bei Albert Einstein," in C. Seelig, *Helle Zeit—Dunkel Zeit* (Europa Verlag, Zurich, 1956), p. 72.

[11] See Erich Neumann, *The Origins and History of Consciousness* (Harper, 1962) for pictures of uroboros symbols from many cultures, and E. O. Wilson, *Consilience: The Unity of Knowledge* (Knopf, 1998), pp. 85-88 and 138-139 on the universality of the fear of snakes among primates and the psychological effects of serpents. "A snake is merely the zoological entity, but 'serpent', as we will see, opens up vast metaphorical possibilities...the bearded serpents of ancient Egyptian and Greek religion; the partly human-bodied cobras with multiple fused hoods, the nagas of Hindu mythology; the horned, winged, hairy, feathered, or fire-spitting species of fable and legend; the basilisk, the dragon..." according to Balai Mundkur, *The Cult of the Serpent: an Interdisciplinary Survey of its Manifestations and Origins* (State University of New York Press, 1983), pp. 2-5. For example, the Hindu god Vishnu sleeps on the coils of Ananta, the serpent of infinity – Richard Cavendish, ed., *Encyclopedia of Mythology* (Little Brown, 1992), p. 25f. In Dahomey in West Africa, the creative force controlling all life and motion is Da, meaning serpent. A Tibetan myth of origin has a female serpent born from the void; the crown of her head becomes the sky, her eyes are the sun and moon, her tongue becomes lightning, and so on creating the world. In many of the oldest creation stories not only of Europe, the Middle East and Asia but of the Americas, there is a Goddess-Mother in the form of a serpent. In Aztec mythology, Quetzalcoatl (the Plumed Serpent) and Tezcatlipoca pulled Coatlicue, the Earth Goddess (Lady of the Serpent Skirt) down from the heavens. Taking the form of two serpents, they ripped her into two pieces to form the earth and sky. Her hair became plants, her eyes and mouth were caves and sources of water, other parts of her body became mountains and valleys. In the Maya creation story, the *Popol Vuh*, in the beginning there was nothing. "Whatever might be is simply not there: only murmurs, ripples, in the dark, in the night. Only the Maker, Modeler alone, Sovereign Plumed Serpent..." A godlike figure spoke to the Serpent, and together they formed the thoughts that became the earth – D. A. Leeming and M. A. Leeming, *Encyclopedia of Creation Myths* (ABC-CLIO, 1994), p. 188.

[12] Galileo Galilei, *Discourses Concerning Two New Sciences* (Great Books, Encyclopedia Britannica, 1952, Vol. 28), p. 187.

[13] Scale models are useful in engineering and biology when the physics of the situation shows how to apply the results from scale models to full-size prototypes. See Thomas A. McMahon and John Tyler Bonner, *On Sixe and Life* (Scientific American Books, 1983).

[14] John H. Holland, *Emergence: From Chaos to Order* (Helix Books, 1998). Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software* (Scribners, 2001). Harold J. Morowitz, *The Emergence of Everything: How the World Became Complex* (Oxford University Press, 2002).

[15] Roger W. Sperry, "A Search for Beliefs to Live By Consistent With Science," *Cosmic Beginnings*, C. N. Matthews and R. A. Varghese, eds. (Open Court, 1995), p.319f.

[16] David Grinspoon, *Lonely Planets: the Natural Philosophy of Alien Life* (HarperCollins, 2003), pp. 223-227.

[17] Niels Bohr, quoted in Ivan Tolstoy, *The Knowledge and the Power: Reflexions on the History of Science* (Edinburgh: Cannongate, 1990).

[18] Richard Dawkins, *The Selfish Gene* (New York: Oxford University Press, 1976; 2nd ed. 1990).

[19] James Lovelock, *Gaia: a New Look at Life on Earth* (New York: Oxford University Press, 1979).

[20] Steven Weinberg, "Two Cheers for Reductionism," *Dreams of a Final Theory* (Pantheon, 1992). P. W. Anderson argues that radical reductionism "breaks down when confronted with the twin difficulties of scale and complexity" ["More is Different: Broken symmetry and the nature of the hierarchical structure of science," Science **177**, 393-396; revised version in *More is Different: Fifty Years of Condensed Matter Physics*, N. Ong and R. Bhatt, eds. (Princeton University Press, 2001)]. Ernst Mayr argues that reductionism has not been a productive approach in biology, in *What Makes Biology Unique* (Cambridge University Press, 2004), pp. 67-82.

[21] The best example we know of is the reduction of the laws of thermodynamics to the statistical properties of large numbers of particles – subsequently discovered to be what we now call atoms and molecules. But like the reduction of electricity and magnetism to quantum electrodynamics by Feynman and others, it is better to view this as an encompassing revolution rather than an example of radical reductionism. Karl Popper, *Unended Quest* (Open Court Publishing, 1974), pp. 269-281, surveys the limited success of reductionism in the physical sciences and concludes that "as a philosophy, reductionism is a failure…we live in a universe of emergent novelty."

[22] For more on this, see, for example, John D. Barrow and Frank J. Tipler, *The Anthropic Cosmological Principle* (Oxford University Press, 1986); John Gribbin and Martin Rees, *Cosmic Coincidences* (Bantam Books, 1989), p.11f; and Martin Rees, *Just Six Numbers: The Deep Forces That Shape the Universe* (Basic Books, 2001).

[23] Strong and weak forces govern both atomic nuclei, on the left of the Uroboros, and stars, directly across on the right. Dark matter is probably made of particles, such WIMPs or axions, which are associated with very small scales – but the gravity of the dark matter holds together galaxies and clusters of galaxies. Grand Unified Theories (GUT) and the hoped-for superstring theory of everything may connect phenomena on even smaller scales with the whole cosmic horizon and beyond. A drawing of the Cosmic Uroboros that Joel used in papers published in 1983-84 showed these connections across the diagram between medium small and medium large scales, between even smaller and even larger scales, and so on.

[24] *Hamlet* III.ii

[25] From an address by Chief Oren Lyons to the Non-Governmental Organizations of the UN, Geneva, Switzerland, 1977, reprinted in Steve Wall and Harvey Arden, *The Wisdomkeepers: Meetings with Native American Spiritual Elders* (Beyond Words Publishing, Inc., 1990), p.71.