OUR UNIVERSE … BUT NOT AS WE KNOW IT

CHAPTERS

Part 1 – Setting the Scene

Our universe … but not as we know it

Our scientific body of knowledge is a tableau of colourfully incongruous crazy paving stones. Each research discipline is an isolated island focussing on a detached part of the world around us, leading to completely disconnected explanations for our society, living things and the material world. Other than the scientific process, there is no underlying rhyme or reason to link them all together. This disjointedness prevents us from resolving some of the most pressing challenges facing mankind.

Let me take you on an intellectual adventure, traversing all the sciences. On our travels, we are going to re-interpret key areas of learning to create anew a beautiful coherent picture of our cosmos. But, be warned. If you stay the journey, it will mess with your head, for we inhabit a truly living universe.

Chapter 1 - Scientific Puzzles

"Some of the simplest questions are the hardest to answer."

Beneath the central monumental dome in the Pantheon in Paris, suspended on a sixty-seven-metre length of piano wire, swings a steel sphere. It is slightly larger than a football and is suspended a few feet above a large circular floor mirror. It floats back and forth, surprisingly slowly, forever accompanied by its metallic reflection. Each arc is five metres, taking the orb seven seconds to glide over the polished surface, passing to and fro, day in, day out, year on year, uninterrupted for decades.

The Pantheon, a majestic stone mausoleum, is constantly thronged by visitors, come to see the tombs of the greatest influences on French history. A crowd of sightseers is usually found standing around the edge of the mirror in the middle, mesmerised by the swinging ball. It is called Foucault's Pendulum. Over the course of each 24-hour day, the plane along which the wire is freely swinging gradually gyrates clockwise of its own accord. To understand this tourist attraction is to realise that it is you, the observer, and the surrounding massive building, which are slowly rotating relative to the line of swing of that sphere. The direction of travel of the pendulum, as it goes back and forth, is fixed in space relative to Earth's axis of rotation. The purpose of Foucault's experiment, first trialled in 1851, was to demonstrate through a human-scale instrument that we exist on a revolving planet.

Indeed, we all live on but a speck of stardust. Those photographs, which have been taken in recent decades from the Moon, show Earth as a captivating blue-green-white jewel in a vast expanse of space - a floating colourful orb against a backdrop of inky blackness. Our home. But, as we go about our day-to-day lives, seeking to eke out an existence, ensuring that we have the money to buy food and cover the bills, stressing about work and worrying about our health and the welfare of our nearest and dearest, it is easy to forget that we happen to be on the surface of a large rock, orbiting the Sun at an incredible speed of 67,000 miles per hour. To each of us, it's so big that it feels as if we're walking around on flat ground. With gravity holding our feet firmly to the floor, we are able to get on with living, oblivious to the universe that's out there.

Until nighttime, and the stars come out.

Living as I do in Western Europe close to the large metropolis of London, there is so much light pollution and smog that you can't see much of the night sky anymore. There's the Moon, the key planets (if you know where to look) and a random speckle of glimmering dots, being the brightest stars. It requires an exceptionally clear night, which only happens on very rare occasions, to catch sight of the Milky Way. I was lucky at an early age to have spent some time growing up in Chile, South America. We, my family - mum, dad, two younger sisters and a very large Alsatian dog and I - used to go camping on the coast, close to the Atacama Desert, relatively near to some of the world's most important space observatories. I vividly remember one evening as a young teenager, spilling out of a restaurant after a delicious pacific sea food chowder, and heading back to our tent under the pine trees. As we crossed the beach, we realised it was an especially clear night, so we lay down on our backs on the warm sand in the chill air and star gazed. It was unreal. Knowing what I was looking at, that enormous universe, the blazing glory of the entire Milky Way and the infinite darkness of empty space around it, I found myself experiencing something akin to agoraphobia. It was so darn immense and awe-inspiring and I was so small and inconsequential. It blew my mind and took my breath away. Everything felt so connected and

I could sense the oneness of it all. It is a moment and emotion that I hope I will always remember.

The sparkling sky, which I observed that night, must have been much the same as that experienced on cloudless nights by our ancestors. With the exception of a few far-sighted philosophers at the library of Alexandria (Egypt) in the days of the Ancient Greek civilisation, the vast majority of people until relatively recently thought we stood on a flat earth, under which, if one dug down deep enough, hell would be found. And then above us were the star-speckled heavens, through which travelled the Sun, the Moon and various other astrological objects. They perceived the night sky as the inside surface of a painted dome, such as in their great temples and cathedrals. They had no notion that the multitude of stars in the night sky were far away suns.

In those days the human population survived in blissful ignorance of the potential for meteor strikes as they fought for good farming land, piously prayed to their various gods, existing in a bubble they called 'the cosmos'. It was their own space that people shared with the birds and the beasts, and, in this domain, Man was boss. Our ancestors' wildest imagination of what they were seeing, when they looked up, fell so very far short of the truth. Frankly, most of them had other things to worry about than the possibility of rocks falling from the sky. But then, winding the clock back around five hundred Earth orbits from today, their innocence was about to be punctured.

In seeking to predict how certain larger stars moved relative to the background constellations visible in the night sky, astronomers in the Middle Ages were inspired to build elaborate clockwork models of their self-contained cosmos. They placed Earth (whether flat or spherical) at the centre of these machines and, using intricate mechanical gearings, portrayed these mobile stars following convoluted circuitous movements, which made little sense. As these wisemen made regular recordings of the sky at night, they tweaked their contraptions to become increasingly complicated, until eventually, one amongst them thought, “Hold on, there’s another way to explain what we are seeing here.” That man was Nicolaus Copernicus. In 1543 he presented his revolutionary ideas and turned everything on its head.

Copernicus sought to challenge everyone’s preconceptions by boldly positing that their night-time observations could be better interpreted by assuming those larger points of light and Earth were, in fact, all planets orbiting the Sun. The heliocentric theory. His proposition would have been quite a shock to anyone living in the late Middle Ages. With other surprising contemporary events, such as the discovery of America – an exotic new land never mentioned in the Bible – along with Ferdinand Magellan's circumnavigation of the world, it was quickly realised by the more enlightened philosophers that Copernicus’ theory might actually be right – that they lived on a relatively small rock hurtling around an inconceivably hot ball of fire and, that contrary to the apparent solidity of the ground under their feet, they were travelling at speed through space. Within a few decades, it became untenable for the various authorities of the day, such as the Catholic Church, to continue to allege that Earth lay at the centre of everything.

The heliocentric theory was elegant. By transposing our viewpoint to a new perspective, Copernicus simplified our understanding of the motions of the planets and simultaneously burst our cosmic bubble, opening up the realisation that we exist on just another planet orbiting a star – and one of many at that. It challenged the presumption that the earthly population were special in the eyes of God. Ever since, we have progressively come to appreciate how scarily enormous is the universe. And from all those pictures beamed back from the Hubble and now James Webb telescopes, indicating how many stars and orbiting planets there are out there, it's illogical to pretend that Earth might be the only place where life exists. The occurrence of life, as we know it, may be statistically improbable in any one solar system, but, given the sheer number of stars in our galaxy (at least a hundred billion, probably many more), astronomers suspect that there could be thousands, possibly even millions, of planets out there harbouring living things. And that's just in the Milky Way, one of trillions of galaxies.

Life has evolved on this planet of ours, to give rise to our society in its magnificent diversity, all eight or so billion of us, eventually leading to me tapping out universal theories on a keyboard, resulting in you reading my words. Over the coming pages, we are going to tackle one of the greatest scientific questions, which, despite our huge technological successes of the last few centuries, has yet to have any adequate answer: why is there such a thing as life? This is not going to be some rehearsal of what you've heard before, some rehash of the science that you learnt at school or university. My intention is to achieve a similar effect to that realised by Copernicus. I'm going to mess with your head, challenge you to think differently, to see things in a new way, to change what you think it means to be alive. If you choose to take up this gauntlet, it has the potential to transform how you perceive yourself and society, thus reshaping how you see the world around you from the microscopic atom to the universe at large. "Are you ready?"

You and I exist! We know this because we communicate with each other, eat, walk and breathe air. We are neither holograms nor programmes in a computer matrix but biological entities made out of matter and energy. So, taking as read that whatever you can see, hear, touch and interact with is real, I propose to take you on a journey that spans many areas of scientific research, revising how we think about society and nature, and challenging our preconceptions about what the universe is made of. We will re-examine core theories on which our sciences are based, including Abraham Maslow's Hierarchy of Human Needs, Charles Darwin's Theory of Evolution and The Second Law of Thermodynamics. We will ultimately take a look at what the science of Quantum Mechanics is really trying to tell us about our universe. I intend to show how some of the foundational assumptions that underpin our accepted modern science can be re-interpreted to enable a more coherent picture of nature and the way the universe works. Intriguingly, this provides an opportunity to converge eastern and western philosophy, but we must travel far before that becomes apparent. It is an alternative viewpoint that fits with that feeling of oneness, which I experienced forty years ago lying on my back on a pacific beach staring at the stars.

"So, where shall we start?" Let's begin by examining a few of the puzzles that, despite the best efforts of many philosophers and scientists over the last century, remain unresolved.

Returning to the recap on how we began to realise the incomprehensible enormity of space, rationally we no longer consider life, even intelligent life, to be extraordinary and now expect there to be other instances in the universe. But, despite the technological advances that have taken place since Copernicus' day, our sciences still can't tell us why life happens. The progress that we've made in the biological sciences in the last fifty years is phenomenal. Tackling the recent Covid pandemic has been a case in point: within a month of detecting a new dangerous virus, Sars-Covid-19, we had mapped its genome and four months later we had crafted RNA strands to insert into our own cells so that they would automatically create antibodies to this disease. Amazing! And it's only seventy years since we discovered the structure of DNA (where DNA represents two RNA strands locked together). With such technological knowhow, one would have thought that we should be able to explain how you get from seemingly inanimate things, such as atoms and molecules of which DNA is indisputably made, to living things, such as bacteria, cells and ourselves. But, somewhat bizarrely, we can't.

It's a long-standing quandary that has vexed the minds of several Nobel Prize winners: we can't properly align our physical sciences, observing the tendency of gases and liquids to become more random, with our life sciences, through which we learn about the growth of highly structured living organisms. By way of example, if like me you are a white tea drinker, then every day you will watch a dash of milk unfailingly disperse through your cup of tea. Beforehand you have two separated liquids (the milk and the black tea), which in the mind of a physicist is the more ordered situation; this can be proven to be the case by mathematicians. With one easy swift motion, you pour in the milk and it mixes of its own accord, to form what is construed to be a more disordered (or unstructured) state – the white tea. Reversing this process, to retrieve the unadulterated milk and thereby create order, would be nigh impossible and, at the very least, take a huge amount of time and effort. Conversely, as a gardener, you might put a seed, which is essentially a collection of molecules, in some soil, add water, and in a short time a plant will emerge. The green shoot pushing up out of the soil is made from not only the molecules in the seed but as it grew it will have extracted the randomly dispersed nutrients from the soil and oxygen and carbon dioxide molecules wandering around in the air. The resultant seedling is a highly organised object, structure emerging from chaos (order from disorder), which took place spontaneously. It just happened.

These mundane observations – milk dispersing in tea and growing plant – seem to be the opposite of each other. And no matter how hard we try, we can't quite reconcile them.

Putting aside our inability to explain why something grows in the first place, we do now have a much better understanding of how living things, once in existence, evolve. Back at the time that Copernicus was alive, it was generally thought that the whole cosmos, including ourselves and all the flora and fauna, came into being some six thousand years ago (as construed from the books in the Bible) and that all the species of animals and plants, since they were created by God as already perfect entities, were immutable. Darwin, of course, transformed our thinking on natural history through his concept 'survival of the fittest' and showed how species change over time. This is now drummed into every child at school as something which is so indisputably true that it is treated as fact. It seems to make sense fundamentally doesn't it – animals battling it out to survive, who dares wins, extinguishing your fellow human, gorilla or insect in the process. Yet Darwin's theory doesn't account for a hugely important factor – cooperation. He himself was fully aware that the purely competitive world, which he depicted, was not consistent with very commonplace phenomena – that you don't have to travel to the Galapagos islands to find – being the beehives and ant nests in your own back garden. And Darwin had only touched upon what we now know about cooperation in nature.

Let's go take a walk in your local woodland. Tramping through the wood, kicking up rotting autumn leaves, weaving between the gnarled trunks of towering trees, which have been there since our great-grandparents were alive, most of us are as oblivious to what's happening beneath our feet as the fact that we are on the surface of a spinning planet. It is now thought that below every footprint, which you leave in the mud, there are some three hundred miles

(!) worth of mycelium. These mycelia are the network of microscopic tendrils of fungi, thinner and more tenuous than tree roots, mostly too small to see with the naked eye. Where you might find the occasional mushroom or toadstool popping up out of the soil, these are just a hint of all the fungi matter that exists just below the surface, stretching out like a huge, connected mesh throughout the forest. Now, here's the remarkable thing that scientists have recently worked out. This mycelial network links up with all those tree roots, enabling the trees to communicate with each other. Yep – trees speak (so-to-speak) to their neighbours. Scientific experiments have proven that, in healthy forests, trees are able to pass nutrients to each other through this network of mycelium. Using a different species as a conduit, the trees are cooperating with each other, looking after those neighbouring trees that are struggling and passing warning signals to each other of predators and disease.

It's not just the obvious places where cooperation is happening, such as human societies, dolphin pods, chimpanzee troops, beehives and much more. Cooperation between different parts of nature is everywhere in every ecosystem. Yet, we gloss over this. It seems to happen in such a multitude of different ways that it has so far been beyond our comprehension. Furthermore, we, and all the creatures that are large enough for you to observe with your own eyes, are universally dependent on cooperation taking place between the cells in our bodies. Multicellular organisms somehow came into existence through emergent cooperation between single celled systems, those which require a microscope for us to see. We just can't fathom out how this happened.

At about the same time that Darwin was sailing around the world in the early nineteenth century gathering data on species from isolated islands in the Pacific, members of the budding community of geologists were crawling over the cliffs of southern England and other areas of exposed rock strata, unearthing peculiar dragon-like fossils – the dinosaurs, as we now know. The jigsaw of evidence that they were gradually piecing together to re-create skeletons of ancient species suggested that our planet and the life on it had been around for an awfully lot longer than the six thousand years previously assumed. We now know that life took aeons of time to establish itself on this planet. For the majority of the estimated four and half billion years that Planet Earth has been in existence, life has been nothing more than sludge – gloop made up of single-celled organisms, each one invisible to the naked eye. This long period was, however, critical in creating the seemingly stable conditions for multi-cellular life, such as ourselves, to take form. Infinite numbers of microbes, through competing and cooperating, established the foundations for self-regulating systems, being multicellular bodies, and at a larger scale the whole global biosphere that, in recent years, we have come to call Gaia – the forests and jungles, ocean life and all those insects, microorganisms and fungi saturating every nook and cranny around the planet. Analogous to the way your body maintains its steady temperature whatever the weather, at a planetary level many feedback processes have developed to help keep our oceans and atmosphere relatively constant.

Whilst the scientific community is rapidly learning about these global stabilising mechanisms, they are far short of fully understanding how these work and, of particular importance, whether these processes are robust enough to withstand us humans trampling all over them. This worldwide interconnected system is reliant on cooperation at a variety of different scales – between buzzing bees pollinating flowers, trees speaking to their neighbours in the forest and all the way up to global circulatory systems, such as our weather and oceanic currents transporting heat and nutrients from one place to another. But, just like those thin threads of mycelium linking the trees in your local woodland, cooperation is frequently very fragile. We damage such natural collaboration, wherever it may be, at our own peril.

Our inability to understand cooperation in nature extends to ourselves – what is it that causes you and I to choose to remain a part of the society into which we are born?

On 27th February 2010, a huge earthquake (magnitude-8.8) took place off the coast of Chile, just south of the capital. It was shortly followed by a devastating tsunami. The previously thriving industrial city of Concepcion, which had a population of a little over 200,000, was badly hit. It became cut off by the damage. Within only a few days, as the population ran out of food, normal law and order quickly deteriorated. *The Guardian* (a British Newspaper) reported at the time: "By late yesterday afternoon the news was filled with images of bands of men armed with rifles, metal stakes and hatchets stalking the streets of the coastal city of Concepción, attacking firefighters, burning a supermarket and adding an air of menace to the already tragic situation." The lessons from this and many other tragedies are that it doesn't take long for civil society to fall apart. When food runs out and people see that their interests would be better met competing instead of cooperating, our illusion of a stable social system quickly evaporates.

Civilised society exists because each of us choose to be a part of it, interacting and cooperating with each other. Yet, we are each individual living organisms, who have our own personal needs to survive, and we will only continue to collaborate in some larger system so long as it benefits each of us to do so. Otherwise, we would all live like cats – alone, competing for food – and there certainly wouldn't be eight billion of us alive. What is it about society that better enables each and everyone of us to meet our needs to survive better than operating on our own? Despite the best endeavours of a multitude of philosophers, pontificating on the nature of humanity, we have yet to understand, even vaguely comprehend, why and how society exists and how it develops over time. In fact, as will be returned to in chapter 2, the latest thinking in sociology completely negates the idea that there is any identifiable progressive change process going on at all. This is despite the fact that people regularly refer to more or less developed countries. Yet, when you dive into the academic world, these notions of levels of development are fiercely debated and largely rejected.

Climate change and other environmental degradations such as destruction of rainforests, depletion of fisheries and plastic pollution - damaging all those natural cooperative worldwide networks - represent existential threats to mankind and the continuance of our civil societies. They have the potential to change the biosphere to make it less conducive to meeting our collective needs. If things were to become difficult, will we continue to cooperate, or will society breakdown, leading to us competing for our survival - reverting to roaming tribal gangs, fighting each other for scraps of food? No film or computer game has yet been able to portray fully the horror of what this would be like. So, if only we could understand a little better why and how we all choose to cooperate and from that what are the underlying mechanisms that have led to the formation and development of society, then we'd be in a better place to tackle the challenges ahead and keep our civilisation intact.

Whilst scientific journals go on and on about the failure to figure out big sexy questions like the challenge to align the force of gravity with quantum mechanics and finding the elusive Dark Matter, in practice resolution of the above far more mundane conundrums - combining our physical sciences (milk dispersing in a cup of black tea) with our observation of the growth of living things, and explaining cooperation in nature and human society - would have a far greater impact on our lives. Perhaps, the answers to these more prosaic puzzles might even shed light on those grander astrophysical enigmas. It's time for some radical thinking to find a way to answer some of these continuing mysteries - why life happens, how to understand cooperation in nature and how does human society evolve. I'm going to take you on a journey to connect the dots together – to formulate a story that brings these different areas of science together under one philosophical umbrella, and which helps explain how we got here. But, beware. Once you've digested this, as per Copernicus' peers some five hundred years ago, you may find the ground under your feet or even the chair under your bottom feels a little less firm as a consequence.

Standing there under the majestic dome of the Pantheon, watching the pendulum and its mirror image languidly travel to-and-fro, it is a little unnerving to appreciate that it is you who are in fact moving and it is the direction of swing of the pendulum that is (at least relative to the Earth's axis) stationary. And so, notwithstanding the huge leaps forward that we have made over the last five hundred years, you are about to find out that the universe we inhabit may not be quite as it appears.

Chapter 2 - Beautiful Fractals

“Everything is a system.”

In the world in which we live nowadays, we are surrounded by objects we refer to as systems – mobiles, computers, cars, fridges, washing machines, central heating and much more besides. Most of us are also part of or regularly make use of what we also commonly call systems – business, transport, sewerage and communications. From an historic perspective, this is a relatively new phenomenon. Go back two hundred years and none of the systems we use every day existed. Furthermore, the social systems, of which the majority of people were a part, tended to be far smaller and simpler – generally, farmsteads run by a family and a few workmen, cottage industries with just a few employees, or aristocratic homes with their upstairs and downstairs. In all cases mostly everyone knew everyone else, if not by name, then at least by face. Larger social organisations were exceptions: for instance armies, navies, boat building and the odd major construction project (such as Paris’s Pantheon). But now we have numerous bureaucratic behemoths – civil services, banks and manufacturing companies – that can extend to hundreds of thousands of employees, in which you might recognise only a small fraction of your work colleagues, wherever you sit in the hierarchy.

Hand-in-hand with these changes to our domestic and working lives, over the last two centuries the way we perceive the universe has fundamentally transformed. Behind the famous technological breakthroughs, such as harnessing electricity, discovering nuclear energy and deducing the structure of DNA, there has been a slow revolution in how we think about things, which now underpins much of modern science. This is the propagation of ‘systems thinking’. In the early twentieth century, this new perspective was formally described by a group of scientists from across the scientific spectrum. However, they were just catching up with a trend that was well underway. Coming out of the Victorian era, these cross-disciplinary thinkers saw systems of all kinds, every which way they looked: biological systems, ecosystems, economic systems, mechanical systems, electrical systems, etc. If only they could decipher some general principles for these things, then they might be able to develop some theory that transcended all those technological fields - a metascience that encompassed all the sciences. By the middle of the twentieth century, a taxonomy of systems had been produced (see Box 2a).

Box 2a - Taxonomy of Systems

1. Static structures, such as bridges
2. Clockworks, such as clocks and the solar system
3. Control mechanisms, such as a thermostat
4. Open systems, such as biological cells
5. Lower organisms, like plants
6. Animals, like birds
7. Humanity, meaning all of us
8. Socio-cultural systems, including families and businesses
9. Symbolic systems, such as God

To say this list is wide ranging is a bit of an understatement. Since then, systems thinking has expanded further. Simply put, we now construe everything that you might identify as a recognisable thing to be a system – from an atom to a rock, from an ant to your pet cat, from a business to a city, from a star to a galaxy.

Given the breadth of things that might be considered systems, it's unsurprising that an easy definition of this concept hasn't been forthcoming. Pretty much any scientist who's dabbled in systems thinking has sought to come up with their own interpretation. At its most simplistic level, most rely on three principal factors:

1. a system is a phenomenon which can be identified, detected or differentiated in some way from its surroundings - a thing.
2. a system interacts with its surroundings.
3. a system is made up of more than one interacting part, where each part could itself be a system.

However, perhaps, the most important notion was conceived by Aristotle, some 2,300 years ago. He essentially coined the oft used phrase: a system is "more than the sum of its parts".

If you were a student in the nineteenth century, you would have learnt that atoms, which form the most basic building blocks of everyday matter, were like miniature ball-bearings. Of course, this was just supposition by leading professors of the day, as there were no powerful microscopes and other kit to enable people to peer into, what we now frequently refer to as, the quantum world of atomic and subatomic particles. Perhaps, what the Victorian scientists were relying on is that if you smash things hard enough, you create smaller and smaller little bits - from gravel to sand to flour … to atoms. So, atoms were not appreciated as being systems but rather seen as solid incompressible, yet minuscule, objects. It is what one might call 'the Lego brick view of nature' - where all larger things, the world that we can see and touch, is constructed out of those very small Lego bricks.

This all changed at the start of the twentieth century through the work of Ernest Rutherford, who was one of the early pioneers to explore radioactive decay and thereby paved the way for our modern nuclear energy industries. He set up an experiment in which he and his research fellows fired alpha particles at a sheet of gold foil. He worked out later that alpha particles were, in fact, naked Hydrogen atoms – single protons without any electrons. What he did immediately come to realise, however, was that the gold atoms in the foil had an internal structure. Many of his alpha particles passed straight through the foil but the occasional one bounced back. This led him to come up with his model of the atom, to which we still hold, with a minute charged centre containing most of the atom's mass, the nucleus, surrounded by much lighter electrons. And so, as a student now you learn that atoms are complex systems with many parts that are constantly interacting internally, while the whole object interacts with the world outside. Atoms clearly match that three-part definition of systems and are more than the sum of their parts.

The Lego brick way of thinking about nature has historic roots in Greek philosophy and went by the term 'vitalism', another idea put forwards by Aristotle. Essentially this construct seeks to differentiate the living world of all things that grow or move of their own accord from everything else – being all those gases, solids and liquids that make up our surroundings, that don't appear to be alive and which we tend to denote as being inanimate. The Greeks perceived that living things had some form of vital energy, which demarcated the animate from the inanimate. Now, despite that we know that atoms are systems, with their own internal complexity and which constantly interact with their environment, much of our modern science is still predicated on the notion that particles of matter, such as atoms, are essentially inanimate, simply responding to the forces (such as electrical or magnetic forces) that are applied to them.

Consider for a moment how you perceive a chair, a table, a kitchen working surface, a knife, a plate, the ground beneath your feet or the walls of your house. You can see where the

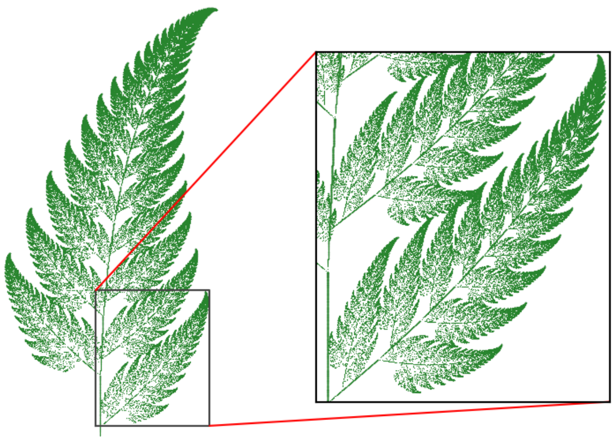
Greeks were coming from. These objects all fit into a category that seems to be rather different to your cat and dog, as they pester for your attention, or your house plants which quickly wilt when you don't water them. All the basic material things can be broken into smaller parts without fundamentally changing their nature; not so with living things, which have a habit of dying when you cut them up. The challenge that we now face, in seeking to understand living systems, is that we've come to realise that they are entirely composed from the same miniature Lego Bricks as everything which is inanimate. So, the question arises - where does this apparent vitality of living things come from?

Take a long hard look at your hands. Study your fingers, nails, the back, and the palm. We all appreciate that our hands contain bones and bleed red stuff if you cut into the skin. But we now know from science that our hands consist of an unfeasible number of atoms making up several hundred billion cells. These cells in turn make up the functional elements – bones, skin, blood vessels, nerves, ligaments, tendons. Yet, somehow, inexplicably, our hands formed naturally and spontaneously from those many trillions of inanimate atoms. And, equally remarkably, our hands maintain their form over time, even though several billion cells are replaced every day. So, every few years you have a completely new pair of hands, yet they're still the same hands. The miracle is that your body is continuously changing, moment by moment, despite remaining structurally coherent.

It is unfathomably beautiful in its intricacy the way that our bodies grow, a magical process of self-organisation, all the components fusing to create the whole – ultimately made from those basic building blocks, the atoms. Feeding this growth are your arteries, which transport your blood with oxygen and nutrients to every one of the cells in your hand to satisfy their energetic and material needs to survive and carry away waste such as carbon dioxide. The two main arteries represent well-defined tubes as they enter the hand, clearly visible when a body is dissected; they then repeatedly branch outwards eventually leading to miniature little blood vessels, so minute in your fingertips they can't be seen with the naked eye. Then these tiny vessels join repeatedly, leading back to those blue veins in your wrist. This ductwork for your blood forms what we now call a fractal network.

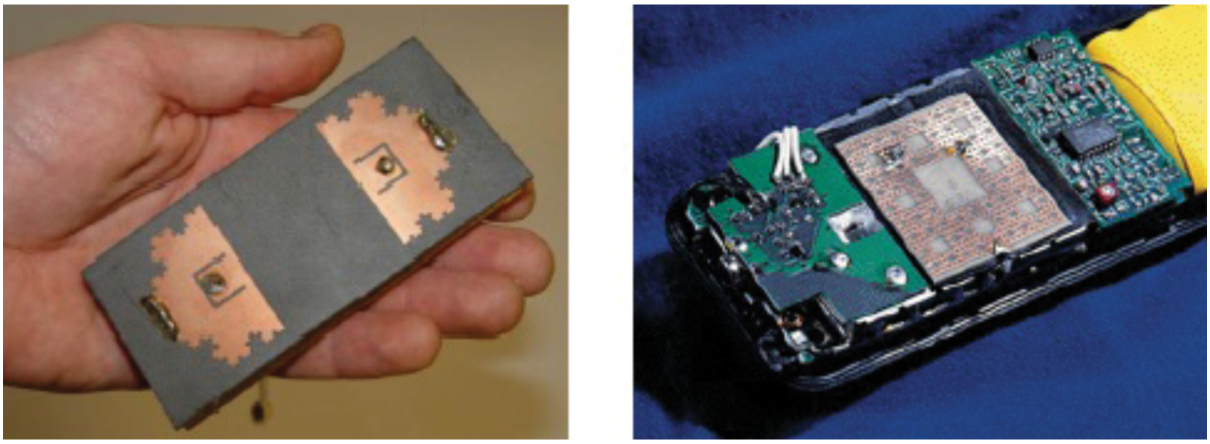
Everywhere you look, you will find fractals. By way of example, almost all plants represent fractal structures (see Figure 2a). Most other organisms have embedded fractals, including the structures of lungs, blood vessel and nervous systems. In domains that we don't perceive as living, fractals can also be found in abundance: for example, snowflakes. And, in the human sphere, the pyramidal structures of those huge bureaucratic organisations - banks, civil services and the like - are also fractal. Thanks to a Polish-French mathematician by the name of Benoit Mandelbrot, we now have the means to mathematically model these elegant systems.

Figure 2a – Plant-like Fractal Structure



In 1958 Mandelbrot, having trained in France, joined the research staff at the American business IBM, a pioneering company credited for reducing the size of clunky huge computers, the size of rooms, to become small enough to sit on desks. This gave Mandelbrot access to computers long before most of his peers. From then, the story of fractal geometry and the advancement of computer technology have run together: your mobile phone no longer needs to have an aerial sticking out of the top of it because that aerial is now designed as a fractal (see Figure 2b).

Figure 2b – Mobile Phones using fractal antennae



In developing his geometry, Mandelbrot worked out that a common theme across all fractals is that you can generate them from simple repetitive instructions, which create geometric patterns that repeat endlessly, creating what is termed self-similarity across a range of scales. This makes them perfect for replicating with computer algorithms to create the landscapes – the hills, the trees, and the river systems - in many modern sci-fi films and computer games. These systems express the same pattern nested inside each scale as you zoom in, smaller and smaller. Sometimes this is exact repetition, as demonstrated by the Sierpinski triangle (see Figure 2c). Self-similarity, on the other hand, is beautifully expressed in the famous fractal named after Mandelbrot himself (see Figure 2d).

Figure 2c – Sierpinski Triangle expresses exact similarity at different scales

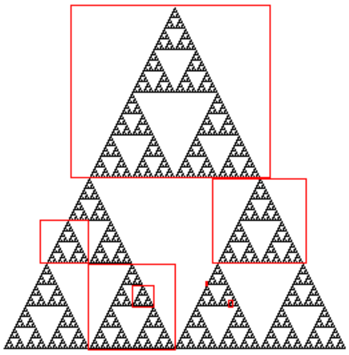
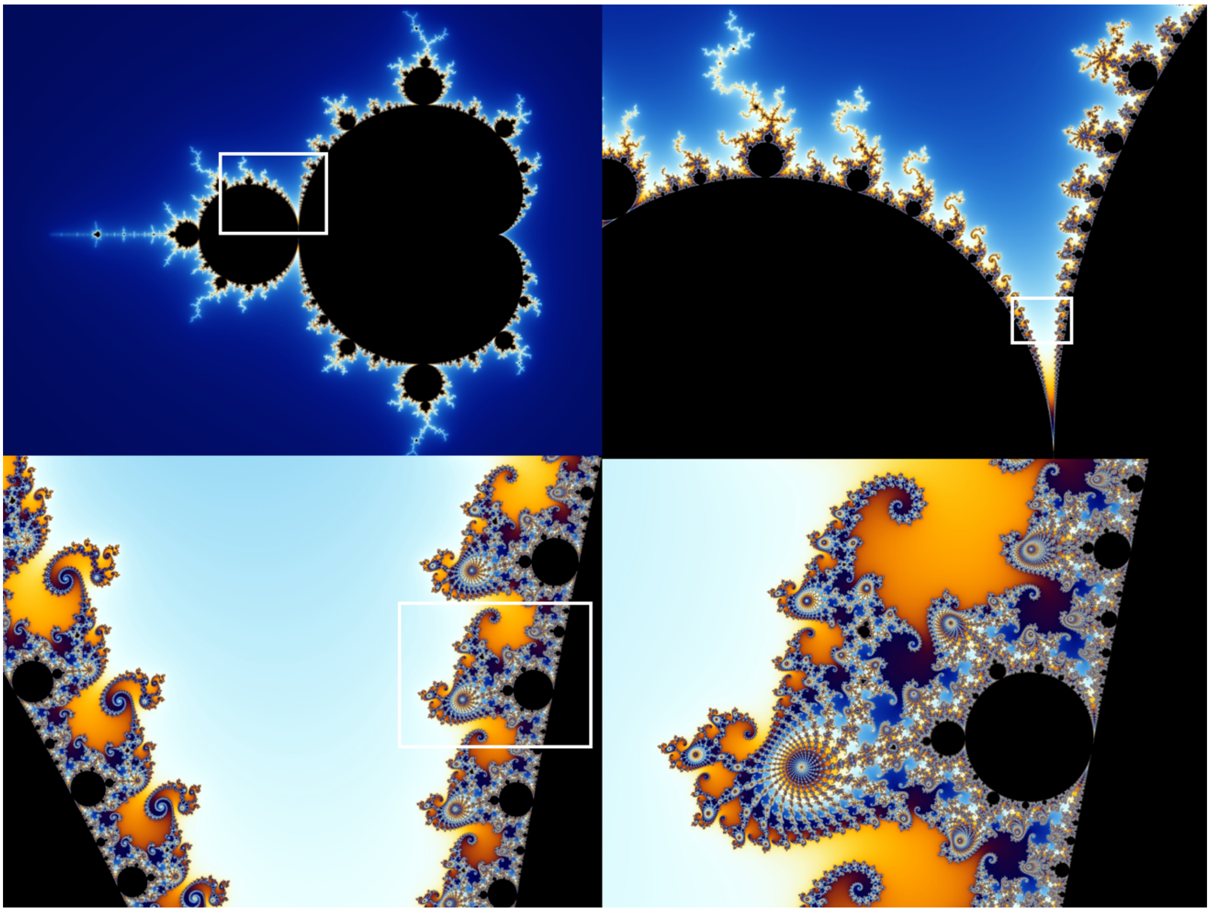


Figure 2d – the Mandelbrot Set displays endless self-similarity



Mandelbrot was one of those lone protagonists largely derided by his peers for his early career, who had a dream to formulate the mathematics to help describe his fascination with things around us in the natural world that aren't smooth or seemingly linear. Where you might perceive the surface of a cloud or the path of a coastline to appear completely random, Mandelbrot was able to show that these non-linear phenomena still follow some form of predictability. His thinking provided the precursor to other concepts that emerged as computational power accelerated, notably complexity theory and chaos theory. These theories concern systems or events, where things don't happen in an orderly manner or which are unpredictable. Within such systems, small discrepancies in initial conditions can rapidly convert into very different outcomes. This gave rise to that idea that the flap of a butterfly's wings might ultimately trigger a thunderstorm - the Butterfly Effect. Numerous books were written on these various new concepts during the 1990s in the expectation that they would help resolve some of those conundrums outlined in chapter 1 – especially our inability to reconcile the spontaneous growth of animate things (say, your house plants) with the tendency for inanimate systems to mix and become disordered (the milk in your tea). Such progress has since stalled, and those big questions are as far from being answered as ever.

There is a common theme, which connects all these attempts to model mathematically the world about us. Whether one is considering the formation of a fractal, such as a snowflake, or large-scale weather phenomenon, such as tornadoes, they all derive from the interplay between huge numbers of component parts – ultimately those atoms and molecules. In larger systems, the interactions are effectively infinite. Yet, despite the innumerable elements, such systems often lead to the emergence of coherent, identifiable objects, such as snowflakes and vortices and many other phenomena. You are just another example of what are collectively called complex adaptive systems. The mathematics behind these universal phenomena shows how relatively simple systems can sometimes exhibit extremely complicated, non-linear (even chaotic) behaviour (see Box 2b). Conversely, very large systems of unimaginable numbers of interacting components can give rise to patterns that, through their symmetry, we tend to interpret as being structured.

Box 2b - Complex Adaptive Systems - the flocking of birds

A good example of a relatively small system, which can achieve very complex behaviour, is that of a flock of birds. There is no lead bird and there is no prescribed routine that the flock is following. Rather, the spectacular displays of starlings soaring and swooping in the evening sky can be modelled in a computer environment through three instructions applied to each imaginary bird, generally referred to as 'boids'. These are that each boid must:

1. steer towards the centre of mass of neighbours;
2. avoid hitting neighbours or obstacles; and
3. align flight (direction and average speed) to match neighbours.

From these three simple rules, convoluted flocking ensues on the computer screen. The complex behaviour of the whole arises automatically from the actions of each individual agent, birds or boids, and does not require any coordinating hand. It is an example of what tends to be referred to nowadays as 'emergence'.

Whilst we now have the mathematics and algorithms to describe and replicate fully formed fractal structures, where our sciences still fall short is an inability to explain how such objects spontaneously grow in nature – all those microscopic atoms or molecules fusing to create a perfectly-formed whole entity. By way of example, how does a snowflake materialise in a cloud in the time of, say, half an hour from next to nothing to achieve a size that you can see lying in the palm of your gloved hand? This doesn't sound very remarkable until you consider this: its speed of growth equates to more grains of sand than can be found on an average Cornish beach joining the growing structure every second (see Box 2c). Yes, every second! And yet, somehow, the whole outcome is an exquisite symmetrical object. When you think of it like that, then the formation of a pretty little snowflake is jaw-droopingly awesome.

Box 2c - Snowflake Growth

An everyday snowflake is formed out of around ten quintillion molecules of water – that's ten followed by eighteen zeros. That number is more than all the grains of sand to be found on all the beaches on our planet! If the snowflake grew steadily over half an hour, then its rate of growth would equate to one quadrillion (1,000,000,000,000,000) molecules of water joining the growing snowflake structure every second. To get a feel for how big this number is, if you live to 80 years that represents only 2.5 billion seconds. You would need close to a million lifetimes to rack up a quadrillion heartbeats.

The mathematics of quantum mechanics explains how a water molecule is structured. From this, the six-pronged structure of snowflakes is easily derived. But, how come its six main branches all grow to about the same length, so quickly? If you ask a physicist how such snowflake forms, he or she will tell you that the process is random - that the formative snowflake simply floats around in the air bumping into a quadrillion water molecules every second. Oh, and these just so happen to latch onto the right points such that the six branches grow at about the same speed to create that final form that you can inspect on the back of your glove as being a pretty-little-symmetrical wonder.

I don't buy it.

The speed, at which snowflakes grow, speaks of a process that must be going on. It is almost certainly a positive feedback process, leading to exponential growth. But that's definitely not how modern physics describes it. So, is there a way to re-interpret our science to enable a rational explanation? There is. But without changing our underlying understanding of the universe around us, we find ourselves bumping straight into our addiction to vitalism. Because to infer that the snowflake formed in any other way than randomly suggests that those water molecules might not be quite as inanimate - acting as Lego bricks - as we currently like to think.

We might now be able to calculate the fractal geometry of a mature oak tree, but how do you get from humble acorn to magnificent oak? When you think about it, the speed of growth of a tree, as it sprouts new foliage in the spring, is just as astounding as that of the snowflake. But we simply don't know how it happens. At the same time as we see nature creating impromptu coherence – leaves bursting forth from barren twigs, frost on a cold winter's morning – a foundation stone of modern physics and chemistry says otherwise. It is the Second Law of Thermodynamics. This states that instead of seeing structure spontaneously emerge from interacting subsystems, we should instead expect to see all things becoming irreversibly dispersed and unstructured over time – such as the milk unerringly mixing into your tea every time you make a cuppa. The Second Law is entirely predicated on treating atoms as Lego bricks. This prevents the physical scientists from being able to understand growth and development in natural systems - they simply cannot explain how sprouts a leaf, an object which is indubitably made out of atoms.

If our physical sciences can't help us understand how things grow and develop, perhaps the social scientists, from psychologists to sociologists, might be able to assist. Unfortunately, they fare little better. Ever since the start of the Age of Enlightenment – a period of history that commenced around the time that Copernicus was alive and which marked the transition from the Middle Ages to the modern scientific era – philosophers and subsequently sociologists have pondered on what might create the perfect society. Numerous ideas have been expounded. Perhaps the one you'd be most familiar with, written during the Victorian era, is that of Marxism which provided the ideological backdrop to communism. After the collapse of the Soviet Union and the fall of the Berlin Wall, utopian visions like this have become largely discredited. As a consequence, young sociologists will now learn that Multilineal Theory is the best description of how human societies evolve.

Multilineal Theory states that the only obvious development over the long haul of history is that of technology. Beyond that, Egyptian, Roman, and modern societies are simply unique. With the exception of the technology that we have invented, there's no identifiable theme to suggest that we, now, can be construed to be any more advanced than those historic civilisations. And despite all the transformations in our own societies over the last few hundred years, such as the formation of democratic systems, the emergence of social security systems, health care and improved equality for many minorities, the social scientists don't perceive these gains as representing progressive evolution. They are just changes.

As will become apparent through part 2, I beg to differ ...

With our enlightened minds, we are acutely aware that human society is just another natural system. We know that such systems have characteristic ways of developing. But our social scientists don't have any concept of how our societies evolve generally, leave alone how they might best advance to address our current global challenges. So, when faced with climate change, rather than suggesting social or cultural solutions, our sociological academics seek to pass the buck back to the physical scientists - to develop technology to help us out of our collective pickle.

So, perhaps we should turn to our life sciences to help. At least the biologists and ecologists do have a notion of development, set out in *On The Origin of Species,* hurriedly written down by Darwin to beat off his contemporary scientific competitors. Since then, life scientists have learnt a huge amount about the living world, explored jungles in all corners of our planet, dove amongst shoals of fish on colourful reefs, investigated the intriguing microscopic world of bacteria and viruses, discovered RNA and DNA and combined all this knowledge to create the 'modern synthesis' of evolution theory. But, alas, this theory focuses almost exclusively on the competition that takes place between organisms in the wild, leading to the survival of the fittest – the fastest leopard, the giraffe with the longest neck, or the finch with the beak most suited to the local food source. As with Darwin's original theory, the modern synthesis struggles to deal with collaboration in nature [Footnote]. As a consequence there is a huge hole in its explanatory power when it comes to trying to explain why and how things grow and develop.

[Footnote. The modern synthesis does seek to consider cooperation in certain circumstances. But the proposed explanations are far from agreed and limited in scope; they certainly don't enable the extension of evolutionary thinking to the human context. This will be returned to in part 3.]

The theories of chaos and complexity, dreamt up during the 1990s and used to create lots of colourful computationally generated pictures, did not in the end resolve the dilemmas within thermodynamics (structure versus dispersal) and have failed to help us understand any better how cooperation arises in the natural environment. However, they have changed the way we see things in general. They have allowed us to become used to the concept of emergence. The more we look at nature, the more we see emergent behaviour arising from the actions of component parts. By way of example, we are increasingly making use of this in the developing field of artificial intelligence. By creating computationally modelled neural networks, we can train these systems (or, more accurately, we can set up systems like ChatGPT to train themselves) to identify patterns within datasets in ways that we could not ourselves pre-empt or design. We are coming to accept, therefore, that complex phenomena can arise from seemingly inanimate (or minimally intelligent) interacting component parts. But we are still very much at a loss to reason why or how.

And, all that said, we are still hooked on the concept of vitality. Whilst we may now appreciate atoms to be systems and not Lego Bricks, the work of the particle physicists at places like CERN, smashing protons together, is all about trying to find ever yet smaller building blocks and the forces that hold them together, from which we might construe our universe to be constructed.

Our worldwide civilisation is a complex adaptive system composed of billions of people all interacting to create the interconnected nation states and economies that exist today. They are structured, yet simultaneously forever changing as people within them are born, grow up, move from job to job, retire and die. But the whole social systems retain their structural integrity and go on - just like the cells in your hand. To survive, our civilisation must continually adapt to accommodate challenges such as climate change, forest destruction, plastic pollution, over-fishing and generally reduce its impact on or work better with the natural systems on which it depends. Our scientific community provides a significant part of the intelligence to think through issues and find solutions. But with these disparate perspectives, the three categories of scientists (social, life and physical) are influenced to respond very differently. In practice, physicists, sociologists and ecologists may as well inhabit different multiverses as concede that there may be any commonality between their disciplines. Working from within their separate silos, they are inhibited from properly collaborating to share ideas to help solve global problems.

The twentieth-century systems thinkers sought to categorise systems in terms of type and function (Box 2a). But there is another way to tackle the objective they set themselves. Instead, one can look at the mechanisms which create complex adaptive systems – what is it that causes billions of pieces (otherwise denoted, agents) to come together, to self-organise to create exquisite wholes and grow? The existence of fractals in nature provides a clue - systems that transcend scales, being self-similar no matter what size you interrogate, and which can be constructed from simple sets of instructions. Note, though, that fractals are just one example of such self-forming systems. Could there be some universal processes which promote the formation and evolution of such objects? Perhaps the way that water molecules coalesce to create snowflakes is no different to the growth of blood vessels in your hand or the formation of large bureaucratic civil services. If this were the case, it would mean that rather than imagining what's happening at the microscopic level of atoms – a scale we can barely see with the best microscopes – we can instead start by looking at a domain with which we are far more familiar: how does human society emerge from all of us?

Once we've worked out how societies naturally grow and develop (part 2), we can start to apply our insights to other aspects of the universe in which we live – the domains of the life sciences (part 3) and physical sciences (part 4). We can then pick up where the systems thinkers left off, to create a meta-science, connecting together those disparate areas of our scientific knowledge – the extant colourfully incongruous crazy paving stones – to achieve a common way of looking at the formation, evolution and nature of systems.

What emerges is a construct, which sees the whole universe in terms of systems within systems within systems, from galaxy down to quark. At each scale, whether galactic, solar, societal, organic or atomic, the same set of destructive and constructive processes are found to operate to create whole entities, which we call 'things'. It is an approach, which matches that sense of oneness, that I felt lying on my back as a young teenager on a chilly Chile beach staring at the stars. And so, as Copernicus did for his peers some 500 years ago, I offer you a new frame of reference.