Caroline Chisholm Sixth form STEM society research articles

23/05/2025

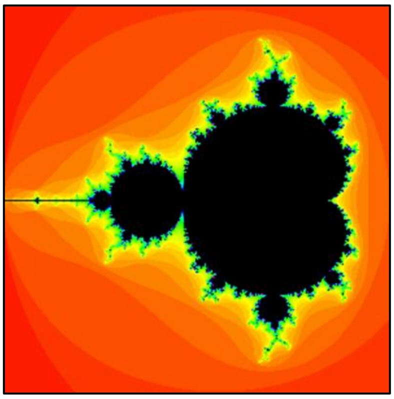
Contents

Fractal geometry – by Freddie Ashbolt

What do snowflakes, trees, the Milky Way and computer signals have in common? At first glance, nothing at all. But as you delve just a little further, a hidden mathematical structure will become clear to you, one which unites them all: fractals. These intricate, infinitely complicated patterns appear throughout mathematics, nature, and even art. But what exactly are fractals, and why are they so important?

Understanding fractals

In their most basic form, fractals are patterns which look the same as you zoom in as they did before. In more detail, they are infinitely self-similar patterns, that are of fractional dimensions - hence the name fractals. Below is the most famous example - the Mandelbrot Set - so try zooming in yourself to understand.



Benoît Mandelbrot was the first to theorize the existence of fractals when he published his book 'The Fractal Geometry of Nature.' In doing so, he defied all assumptions made by classical mathematics, which relied on straight lines and concrete shapes. This traditional geometry assumes things such as: mountains are no more than cones, and clouds are spheres. But in reality, nature is much more. At first, this may seem obvious, yet it highlights a fundamental shift in mathematics.

Mandelbrot's ideas embraced that which classic mathematics shied away from, revealing that much of nature is fractal-like – composed of repeating patterns at different scales. For instance, if you were to zoom in on a mountain, you would continue to see smaller peaks and ridges, echoing the whole.

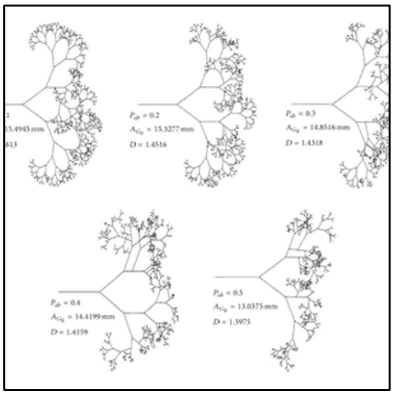
Fractals in nature

While many mathematicians initially dismissed fractals as 'not real mathematics', their presence in the natural world is undeniable. Nature does not conform to the 'smooth' rules set by classical geometry - it has a 'roughness' to it, as put by Mandelbrot. By this he means that trees, mountains and coastlines are not so simple that one could zoom in and see a smooth surface, but rather an intricate, repeating, self-similar pattern. They are alike to fractals.

The most famous example of this would be the coastline paradox, first proposed by British scientist Lewis Richardson. He observed that the coastline of a land mass cannot have an accurately defined length. Although to most this may sound puzzling, it is a key example of the difference between Mandelbrot's fractal geometry and the traditional. If you were to measure the coastline in decreasing increments, as displayed in the graphic above, you'll notice that the measured length of the coastline would increase, tending towards infinity. To make sense of this, Mandelbrot introduced the fractal dimension - a way to define shapes that are too irregular to neatly fit into definitions of '1D, 2D or 3D'. Fractal dimensions allow mathematicians to assign a dimension between the 1st, 2nd and 3rd. For a coastline, the fractal dimension might be something like 1.25. This means it is more complex than a line (‘1D’), but it does not fully fill a flat surface (‘2D’). The higher the number, the more irregular and detailed the shape is.

Fractals in Medicine

Medicine is a more obscure area in which fractals are relevant. It is most particularly in cardiology where Mandelbrot’s ideas are vital, saving lives. When heart rate data is graphed, it exhibits fractal scaling. This means that the graph is self-similar through smaller and smaller time scales. This discovery has helped cardiologists identify subtle, hidden rhythms in the heart which traditional analysis may miss. For example, fractal analysis is crucial in diagnosing atrial fibrillation - where it can reveal a hidden structure in what would otherwise seem chaotic. However, this is not the only way in which fractals play a role in medicine. In ultrasound imaging, they are used to spot malignant tumours. Healthy blood vessels in organs such as the kidney exhibit a branching, tree-like structure. In contrast, malignant tumours often have more chaotic and irregular blood vessel patterns - they are of a higher fractal dimension.

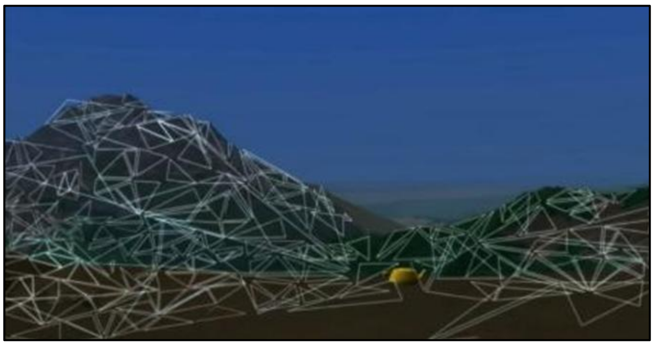


This key difference, highlighted by fractals, can be caught early on by doctors, improving patient outcomes.

So, as you can see, fractals are powerful tools in medicine, used also in neurology, research into tissue regeneration and more.

Fractals in Technology and Film

Fractals are also prevalent in technology and film. Mandelbrot worked at a computer technology company known as IBM. It was here where he was tasked with investigating why computer signals sent via phone lines were often failing. When he graphed the strengths of these signals over time, he noticed something significant: the signals were self-similar, independent of the time scale. This was a clear example of fractal behaviour in technology. This discovery helped IBM better understand and manage signal interference problems and is a concept still relevant in digital communication systems today. Fractals have also transformed computer generated imagery. For example, Loren Carpenter is a computer graphics developer, and he read some of Mandelbrot’s work. Carpenter applied fractal principles to generate revolutionarily realistic landscapes. It worked by a computer beginning with large triangles to represent mountains, then repeatedly dividing each into four smaller triangles, and so on until it captured the jagged complexity of nature. This method proved to be far superior to any traditional techniques.



Carpenter’s fractal-generated terrain was first used in adverts for Boeing and later made a huge impact in ‘Star Trek’. This breakthrough helped launch a new era of visual effects, and fractals are still widely used in film- and game-development today.

The Bigger Picture

From the complex patterns in nature to the hidden structures in medicine, technology and film, fractals present a compelling link between mathematics and the world around us. What began as a simple idea, discarded by traditional mathematicians, has grown into a powerful tool across many fields. Whether it’s analysing medical scans, generating accurate landscapes, or simply marvelling at the natural world, fractals can remind us that there is often order in the seemingly chaotic. Their beauty does not lie in their appearance, but in the insight, they give into how our universe is built.

Dark Matter and Dark Energy – Where Did It Come From? – by Adam Whelan

Despite all visible matter in the universe—from stars to planets—being easily observable, it accounts for less than 5% of the universe's content. The rest is dominated by two mysterious substances: dark matter and dark energy. Dark matter, although invisible, is detected through its gravitational effects on galaxies and clusters. Even more dominant is dark energy, a force pushing the universe to expand at an accelerating rate. Astronomers like Brian Schmidt, Saul Perlmutter, and Adam Riess played key roles in uncovering this. Together, dark matter and dark energy shape the structure and evolution of the universe, but their true nature remains one of science's biggest mysteries.

Using Gravity

The first evidence for unseen matter came from studies of gravity. In 1919, British astronomers Arthur Eddington and Frank Dyson tested Einstein's theory of general relativity by observing starlight bending around the sun during a solar eclipse. This confirmed that massive objects could bend light, a concept known as gravitational lensing. However, the sun was too small to act as a lens on a galactic scale. In 1933, Fritz Zwicky observed the Coma Cluster, located 300 million light-years away. He found that the galaxies were moving far too fast to be held together by visible matter alone. According to Newtonian Physics, the cluster should have torn itself apart. Zwicky proposed the existence of "dunkle Materie" or dark matter—an unseen mass providing the necessary gravitational pull. Although ignored at the time due to his controversial reputation, Zwicky's findings were later confirmed by others.

In the 1970s, Vera Rubin and Kent Ford studied the rotation of spiral galaxies like the Milky Way. They expected that, like planets in our solar system, stars would orbit slower as they moved further from the galactic centre. Instead, Rubin found that rotation speeds remained constant throughout the galaxy. This indicated the presence of dark matter in a halo surrounding the galaxies. Gravitational lensing offered further support. In 1979, astronomers observed a quasar (Q0957+561) that appeared twice in the sky. It was actually one quasar whose light was bent by a massive galaxy in front of it. This gravitational mirage confirmed Zwicky's earlier prediction about galaxy clusters acting as lenses due to dark matter. Today, thousands of gravitational lenses have been observed, often revealing far more mass than visible stars and gas can explain.

Further evidence for dark matter comes from the structure and movement of galaxy clusters, flows of galaxies, and hot gas trapped by gravity. These all require more gravitational influence than visible matter provides. This shows that dark matter is everywhere and is crucial for holding the cosmos together.

The great sculptor

In the 1970s, astronomers began mapping the positions of galaxies, revealing that they were not randomly distributed but formed part of a vast cosmic web. Galaxies were connected by filaments, with enormous voids in between, giving the universe a sponge-like appearance. By the 1990s, John Huchra and Margaret Geller had charted 18,000 galaxies. Today, over one million have been mapped. These maps showed that galaxy structure arose from tiny density ripples in the early universe, written into space by a burst of inflation shortly after the Big Bang. Initially, the universe was hot, dense and smooth, composed mainly of hydrogen and helium. However, dark matter, unaffected by radiation, began clumping first due to gravity. Even the smallest variations in density allowed dark matter to pull surrounding gas into dense regions. After around 100 million years, the gas cooled and fragmented, leading to the birth of the first stars and galaxies within dark matter halos. Over billions of years, these halos accumulated more matter, forming complex structures we observe today.

Simulations using supercomputers show how dark matter acts as a framework upon which galaxies form. Without it, stars and galaxies would have struggled to assemble. This dark matter had to be cold (moving slowly), so it could clump rather than spread out. These findings underscore that dark matter has been a fundamental influence in sculpting the universe.

What is dark matter?

The exact nature of dark matter remains unknown, though several candidates have been proposed. In the 1930s, Wolfgang Pauli noticed inconsistencies in beta decay, where emitted particles carried different amounts of energy. He proposed an invisible particle, the neutrino, to account for this. Neutrinos were later discovered and found to be incredibly abundant, but too light and fast-moving to be the source of dark matter.

Another theoretical candidate is the axion, a particle predicted by the Peccei-Quinn mechanism, which aimed to fix a flaw in quantum theory related to symmetry. Axions are thought to be extremely light, neutral, and rarely interacting with other matter—an ideal dark matter candidate. However, no axions have been detected, even with advanced equipment like the Large Hadron Collider.

Other models suggest dark matter could self-annihilate, similar to how electrons and positrons convert into photons. Physicists also propose that dark matter and dark energy may be connected through a “dark sector” of physics—an entirely separate framework of particles and forces. Despite many theories, no experiment has yet provided a definitive answer.

The great Repeller

Dark energy, discovered in the late 1990s, added a new layer to cosmic mystery. Einstein initially introduced a “cosmological constant” to keep the universe static, as he believed it was unchanging. Later, Edwin Hubble’s observations showed that galaxies were moving away from each other, indicating that the universe was expanding. Einstein abandoned the constant, calling it his “greatest blunder.”

However, new observations of distant supernovae revealed that the expansion was accelerating, not slowing. This could only be explained by a mysterious repulsive force—dark energy. Einstein’s cosmological constant returned to explain this anti-gravity effect. Dark energy isn’t made of matter or radiation. Instead, it appears to have a constant density, unaffected by the expansion of space.

Initially insignificant, dark energy became dominant around 5 billion years ago as matter thinned out. Since then, it has driven faster and faster expansion. In the far future, galaxies outside our local group will be pushed beyond our observable reach. The universe will continue expanding, becoming colder and darker.

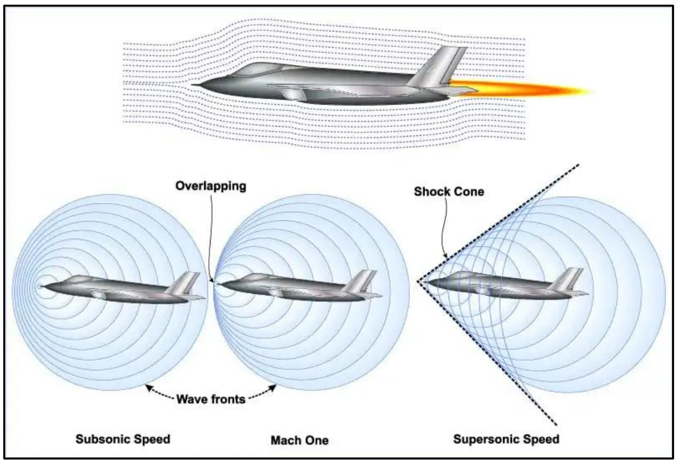
The greatest mystery in cosmology

Dark energy raises even more questions than dark matter. According to quantum mechanics, even empty space has energy due to random fluctuations allowed by Heisenberg’s uncertainty principle. This vacuum energy creates a measurable tension. However, when physicists calculate the amount of this energy, it overshoots the observed amount of dark energy by a factor of 10^{120}—one of the largest discrepancies in science.

Some theories suggest that dark energy could be linked to a mysterious field from the early universe called the inflation, which caused rapid expansion after the Big Bang. Others believe dark energy and dark matter might interact or originate from the same unknown physics. It is even proposed that the “dark sector” could have its own particles and forces, just like the familiar atomic world. But with limited observational evidence, all these ideas remain theoretical.

The challenges of hypersonic flight and its potential in commercialised aviation – by Mischa Khistria

Today's commercial aircraft can travel just below the speed of sound, 330 m/s, which can also be known as Mach 1. The word Mach followed by a number refers to the number of times faster an object can move faster than the speed of sound. Typical commercial aircraft such as the Boeing 737 MAX can travel at 0.79 Mach while some of the faster commercial aircraft – like the Airbus A380 – can travel at speeds of up to Mach 0.85. However, aircraft currently exist that can exceed Mach 5, and these are called hypersonic aircraft, but will these one day replace our existing commercial aircraft?

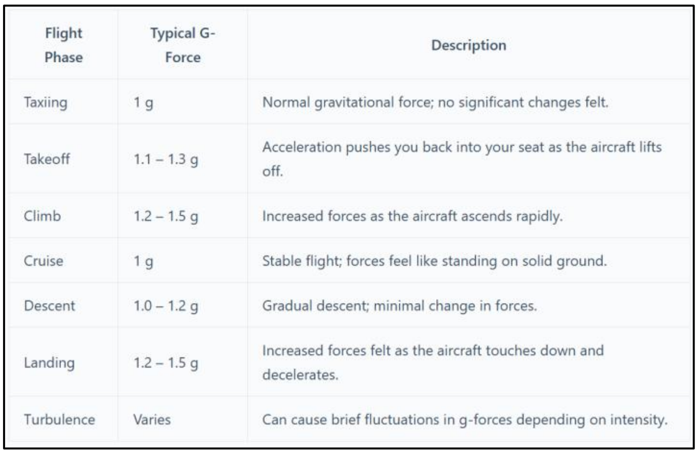


There are many issues surrounding the commercialisation of hypersonic aircraft, such as the aerodynamics and fluid mechanics of the actual plane. The molecules surrounding the plane will break apart due to the high temperatures around the plane, causing an electrically charged plasma to be produced causing a density difference. This rapid shift in density forms a shockwave. A shockwave is an area of compressed air moving faster than the speed of sound. In hypersonic flight, the shockwaves are extremely strong so the air around our aircraft heats up rapidly reaching temperatures of up to 1000 degrees Celsius. This in turn would cause change to the materials used To build the aircraft as they would need to withstand melting meaning we would have to find a more suitable material to build with. Of the newer materials that has been brought into the manufacturing world is ceramic matrix composites (CMC's). Currently they are used on the nose cone, wing edges, engine linings, nozzles and heat shields. Due to the high temperatures reached by all these components, if we were to commercialise hypersonic aircraft, we would still have to use CMCs to maintain the integrity of the aircraft so as not to compromise the safety of the passengers.

The next issue engineers would have to tackle is fuel. Current commercial aircraft use jet A-1 fuel which is a kerosene-based fuel used for its properties such as high energy density, low freezing point, availability and cost effectiveness. As of the week ending April 4th, 2025, global average jet fuel price stood around $91.18 per barrel jet of fuel (equivalent to 159 litres), or approximately 57 cents per litre. This makes it an economically feasible option for commercial use as well as the fact that as of 2024, the aviation industry accounts for 2-3% of the world's CO2 emissions; however, if we were to make the switch to hypersonic aircraft, we would need a new fuel type which could potentially cause an increase or decrease to that statistic depending on what fuel type is chosen. Two examples of these fuels that have been used with existing hypersonic aircraft are JP-7 fuel and the JPTS fuels which are used due to their properties such as low freezing points and higher thermal stability. In 2018 the fuel JPTS was priced at $4.63 while JP-7 was at $9.57 per gallon (equivalent to $1.22 and $2.53 pr litre respectively). This sets the price points for current kerosene-based aircraft very much below the proposed fuel usage price for hypersonic aircraft. The difference in price is due to the properties of the hypersonic fuel and their limited production; however, regarding carbon emissions, JPTS is the cleaner fuel as it undergoes more processing to get rid of impurities.

Lastly, we must consider passenger safety and g-forces. g-force is the measure of acceleration due to earths pull where 1g is equal to 9.81

N/Kg. On a typical flight we experience approximately 1-1.5g’s. During other hypersonic flights such as the North American X-15 the pilots experienced around 5-6g’s and on the SR-71 blackbird flight (a supersonic flight not hypersonic) the pilots experienced 2-3g’s. The typical amount of g’s a human can tolerate is 5g’s after which they experience physical symptoms such as tunnel vision, dizziness or even loss of consciousness.



Flight Phase	Typical G-Force	Description
Taxiing	1 g	Normal gravitational force; no significant changes felt.
Takeoff	1.1 – 1.3 g	Acceleration pushes you back into your seat as the aircraft lifts off.
Climb	1.2 – 1.5 g	Increased forces as the aircraft ascends rapidly.
Cruise	1 g	Stable flight; forces feel like standing on solid ground.
Descent	1.0 – 1.2 g	Gradual descent; minimal change in forces.
Landing	1.2 – 1.5 g	Increased forces felt as the aircraft touches down and decelerates.
Turbulence	Varies	Can cause brief fluctuations in g-forces depending on intensity.

Even at 2-3g’s passengers who are untrained would feel discomfort which just isn’t feasibly if passengers will be subject to that discomfort for long periods of time

To combat this high g-force during take-off, we could extend the runway as linking this to equations we can see that (final velocity-initial velocity)/time=acceleration and by increasing the runway length we are increasing the time over which the velocity is changing and so decreasing the acceleration. This then means, according to newtons second law where Force=mass x acceleration, since the acceleration is less, the force will be less on the passengers. Although, increasing runway length at existing airports wouldn’t be easy as we are limited by existing infrastructure. The only feasible option would be to build new, longer airstrips in rural areas where airstrips could be stretched out longer; however, factors such as noise pollution would have to be considered as (as previously mentioned) sonic booms are an issue with hypersonic flight and they are measured at 110 decibels (with a normal human voice being measured between 55-65 decibels). This would also cost billions of pounds which not every country

destinations that are available to passengers.

Hypersonic flight holds the potential to revolutionize commercial air travel by drastically reducing flight times on long-haul flights and, potentially, decreasing carbon dioxide emissions through improved efficiency and alternative propulsion technologies. This breakthrough could reshape the way we think about global travel, making it possible to travel between continents in a matter of hours. However, the path to commercial adoption still faces many challenges. Overcoming the extreme aerodynamic forces encountered at hypersonic speeds, developing sustainable and high-energy fuels, and ensuring the safety and comfort of passengers under intense thermal and mechanical stress are all things that would have to be thought about. In addition, infrastructure such as airports and air traffic control systems would require significant updates to accommodate such advanced aircraft. Despite these barriers, ongoing advancements in aerospace materials, fuel technology, and airport design are steadily pushing the concept closer to reality. With continued investment and innovation, hypersonic commercial flight is becoming increasingly viable.

Why rollercoaster loops aren’t circular – by Joshua Turner

Going to a theme park, you will most likely notice all kinds of roller coaster loops, but are they actually circles?

A rough start

If you open any physics textbook, you’ll probably find a diagram of a roller coaster with a perfectly circular loop. It’s a classic way to show how forces work during a ride. But in the real-world, roller-coaster loops are not perfect circles. Real designers learned long ago that using a simple circular shape causes major problems - ones that left early thrill seekers bruised, battered, and sometimes too scared to ride again.

The trouble all comes down to forces. In a perfect circle, as the train speeds up and slows down, riders would experience wild swings in how heavy or light they feel. At the bottom of the loop, they would feel almost crushed under their own weight. At the top, they would feel almost weightless - or worse, like they’re being thrown out of their seat. These extreme changes aren't just uncomfortable; they’re dangerous. In the 1840s, Europe built some of the first looping coasters using circular designs, but they quickly realized they were much too harsh. It wasn’t until the 1970s that engineers figured out a better shape that made loops safer and more thrilling at the same time.

From lift to launch

Roller coasters gain their speed through gravitational energy. As the train is lifted up the first hill, it stores energy simply by being up high. As it rushes downwards, that energy is transformed into motion. The higher the starting point, the faster the train can move.

This speed is critical for surviving the loop; the train needs enough speed to get up and over without stalling or falling back. Inside the loop, riders experience something called centripetal force, which pulls them toward the centre of the curve. Along with gravity, this creates the thrilling sensation of being squashed into your seat or lifted out of it. But in a simple circular loop, the sudden changes in speed and direction cause the forces on the riders to swing too dramatically.

Graphing the thrill

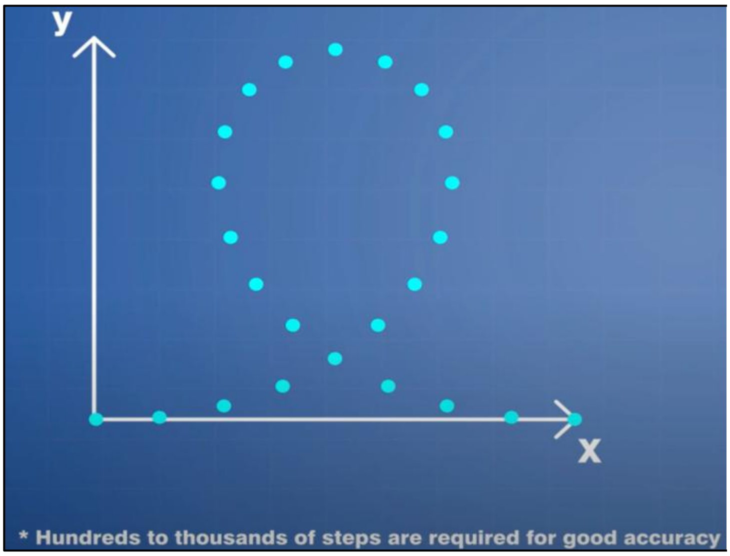
To fix this, engineers stopped using simple circles and instead used special curves. These curves gradually change shape as the train moves through the loop, making the forces rise and fall more gently. Riders still feel intense excitement but now the forces feel controlled, not brutal.

One of the smartest tools designers use today is graphing. Instead of drawing loops freehand or guessing the best shape, engineers model loops using detailed mathematical graphs. They plot how high the track should be at every point, how fast the train will be moving, and how much force the riders will feel at each moment. By using graphs, they can make sure that forces change smoothly rather than suddenly.

Eulers method

A key technique used to model the perfect loop shape is called Euler's Method. It's a clever way of solving problems step-by step. If you imagine trying to figure out the shape of a roller coaster loop, you can't just draw the whole thing at once. Instead, engineers divide the loop into tiny sections. For each small step, they predict how steep the track should be, how tight the curve needs to be, and how fast the train will be moving. Then they move a tiny bit further along the track and repeat the process. Over time, all these little steps build up into a full, smooth curve that looks effortless but is the result of thousands of calculations.

Using Euler's Method, they can make sure that no matter where you are in the loop, the forces are kept within safe, thrilling limits. They can adjust the start of the loop to be gentle, tighten the curve in the middle for excitement, and open it back out at the top so that riders don't feel like they're about to fly off the track.



Another reason graphs are so useful is that engineers can simulate the entire ride before a single piece of track is built. They can test different loop sizes, heights, and speeds on a computer to find the perfect balance between thrill and safety. If one version of the loop creates a force that's too strong, they can tweak the design slightly changing the curve by just a few degrees and instantly see how that affects the forces riders would feel. This helps save money for the roller coaster manufacturer and resources since they don't have to waste time building it to find out if they are safe forces for the rider. Modern safety standards also play a huge role. Organizations like ASTM set clear rules about how long riders can experience high forces. For example even if riders can handle four times their body weight for a short moment, they cannot experience it for too long without risking injury. Graphs and calculations allow designers to stay within these limits, ensuring that rides deliver maximum thrills without pushing riders' bodies too far.

Taking everything into account

Ultimately, the evolution of roller coaster loop design is a testament to the power of physics, engineering, and innovation. By moving beyond simple circles and embracing precise mathematical modelling, designers have crafted experiences that are not only thrilling but also safe, providing that when science meets creativity, the results can be truly exhilarating.

The physics of safety: How cars ‘see’ using radio Waves – by Lisa Owen

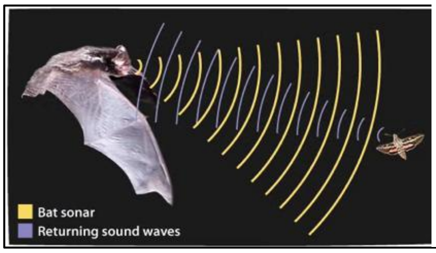
Imagine a future where a self-driving car is constantly working to protect you from unexpected dangers. You might argue that this futuristic notion is safer than navigating today’s UK roads – especially when considering the 1,695 fatalities in just one year. And that may well be true. However, none of this would be possible without one crucial component: radio waves.

What are radio waves and how are they used in radar?

Although first theorised in the field of electromagnetism in the mid-1860s, radio waves remain at the forefront of our day-to-day communications: think of Wi-Fi, mobile phone calls and even your TV. As a form of electromagnetic (EM) radiation, radio waves are typically produced by oscillating electric charges like electrons, in transmitter circuits. These oscillations create alternating electric and magnetic fields, combining to form electromagnetic radiation, including radio waves.

Among all types of EM radiation, radio waves have the lowest frequencies and longest wavelengths – usually greater than 1 mm, roughly the diameter of a grain of rice! These integral properties allow them to travel over long distances and interact differently with various objects, making them incredibly useful in radar and sensing technologies. Furthermore, like all electromagnetic waves, radio waves can travel through different mediums - or even a vacuum – at nearly the speed of light in air.

Due to these attributes, radio waves are ideal for use within radar systems to detect and identify objects. Let's consider of a similar principle, bats navigating and hunting in complete darkness. They use ultrasound (high frequency sound pulses) to listen for returning echoes that bounce back off objects. These reflections allow bats to determine the size, shape, and distance of their surroundings – known as echolocation. Radar systems operate on a remarkably similar principle, except they use pulses of EM radiation, instead of sound. Typically, this system consists of a transmitter to send out the radio signals And a receiver to capture any reflected energy, allowing the radar to build a picture of its environment.



The role of radar in collision detection:

Radar - an acronym for Radio Detection and Ranging - has become a fundamental part of modern driving systems, featuring prominently in Advanced Driver Assistance Systems (ADAS). This enables cars to process real-time data for navigation and obstacle avoidance, functioning reliably in all weather conditions. In vehicles, radar systems have three key functions:

1. Enhancing safety: by detecting objects and potential hazards in the vehicle’s vicinity.
2. Improving efficiency: by calculating the distance and velocity of surrounding objects, it enables the car to adjust its own speed and fuel efficiency.
3. Increasing functionality: unlike cameras, radar remains effective in poor visibility conditions such as fog or rain

By utilising this technology, 360-degree awareness can be achieved, alerting the driver of any potential dangers. A key example is the

Automatic Emergency Braking (AEB), a crucial ADAS feature that can autonomously apply the brakes, significantly reducing the time it takes to respond. In doing so, it helps to prevent accidents or reduce their severity.

The future of cars:

Looking into the future, the real question becomes: “What will the future of self-driving cars look like?”

We can already see, with current advances, that radar will be expected to play an even greater role as we transition toward fully autonomous vehicles. These aren’t just sci-fi concepts anymore, the visions of more aerodynamic exteriors, shape shifting alloys and lack of steering wheels, are slowly edging into our reality.

Companies such as Tesla, Waymo (formerly Google Self-Driving Car Project) and even traditional car manufacturers are paving the way for a fully autonomous driving future – everything from country roads to city traffic, all without human input. Waymo’s robotaxi service, operating under level 4 automation, meaning that these vehicles do not need a human driver, although manual override is possible, provides over 250,000 fully autonomous paid journeys weekly. As of 2025, they are operating approximately 1,500 vehicles, with their core being the Jaguar I-PACE. These all-electric SUVs would not be able to offer such an elevated level of safety without the 29 high-resolution cameras, 4 LiDAR units (utilising light and lasers) and the 6 radar sensors, allowing the vehicle to detect objects up to 1,000 feet away.

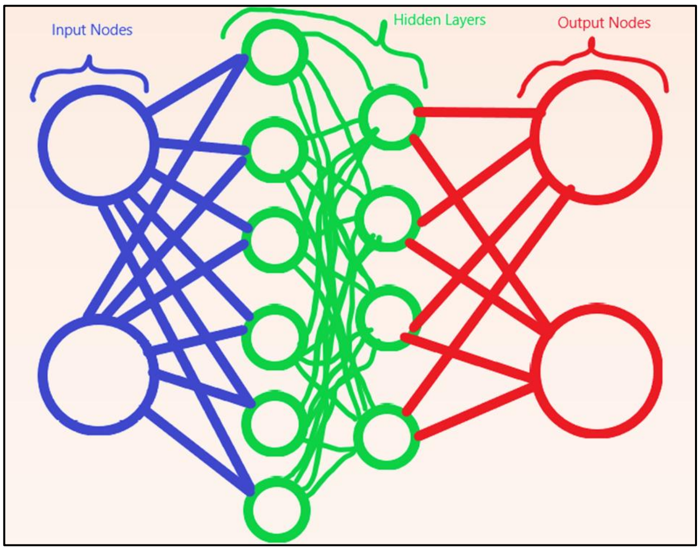
Waymo is only one of many companies showing how radar has the capacity to work alongside other sensors to advance autonomous driving technology. Together with developments within STEM, radar will form a vital component in creating new, sustainable, safer ways to navigate and – eventually – allow for travel without a human behind the wheel.

“Artificial intelligence” and you! – by Richard Razzell

“Artificial Intelligence” seems to be everywhere in Computer Science these days, and is even becoming more prominent in every single field of science. At this point, everyone has heard of these “Artificial Intelligences”, there is a high chance you’ve interacted with them: ChatGPT, CoPilot, Gemini and whatever other advert you’ve seen online about how “AI” will revolutionise your life.

But just how does “AI” work? How is a single thing managing to discover hundreds of new proteins fasters than humans can; identify various cancers in their early stages; befriend your grandma with long conversations; create images which get harder and harder to distinguish from reality every day; and also spread misinformation all at the same time?

The answer is that it doesn’t. All of these “Artificial Intelligences” that you hear about are actually vastly different architectures. What do I mean by architectures? Well it’s quite similar to physical architecture. With wood, bricks and cement, you could build all sorts of buildings, from sheds, to bungalows, houses and even entire complexes. It’s the same with “Artificial Intelligences”, or as I shall be calling them for the rest of this section: Neural Networks.



Neural Networks are made up of Neurons, connections, weights, biases, activation functions and more. They can be arranged, rearranged, edited and set up to create vastly different neural networks which each specialise in different tasks. Unfortunately, going over every single architecture would not only take a few hundred pages, but would also be outdated by the time I finished writing this.

As such, in this section, we are going to cover the most basic form of neural network to get a gist of how exactly neural networks work.

To start off with we have to understand that neural networks are made up of neurons arranged into layers.

The very first layer is the input layer, this is where we put in our initial values; e.g pixel brightness/colour, time of day, sell volume on the stock market, etc.

The final layer is the output layer which we then use to construct our output; e.g which pixels should be at what brightness/colour, how much water should the plant get, how many stocks should be bought right now, etc.

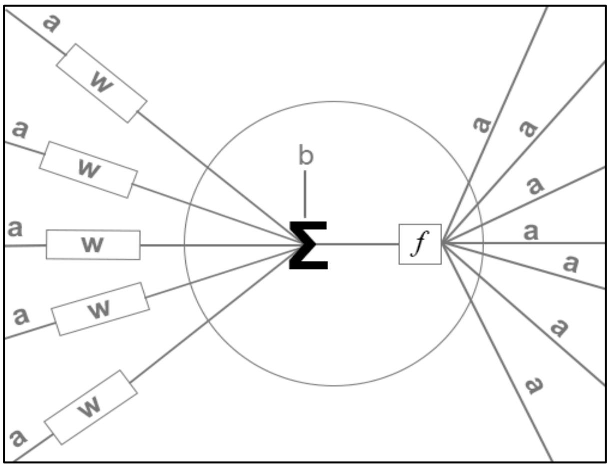
In-between these layers, are what are known as the hidden layers, which can be between 1 and hundreds of billions of neurons, in anywhere between 1 and around 120 layers as of April 2025.

And in-between each of these layers, are the connections. For this model, every single neuron in one layer, is connected to every single other layer in an adjacent layer.

This is of course, all a generalisation of our basic neural network. As said earlier, these days, some neurons aren’t connected to other neurons; but also sometimes, you even get neural networks, choosing other more specialised neural networks to take the data and process it (This is called Mixture Of Experts); or even neural networks feeding themselves their own outputs until a condition is met (This is Steps in diffusion architecture).

Moving on, now that we understand the wide scale of the neural network, it’s time to delve in deeper. We have already discussed the existence of neurons, how they connect to each other between layers, and how they are the building blocks of neural networks. However, we haven’t really discussed what they are. The reason why? Because they’re complicated. It’s because they’re a bit complicated.

This is a neuron:



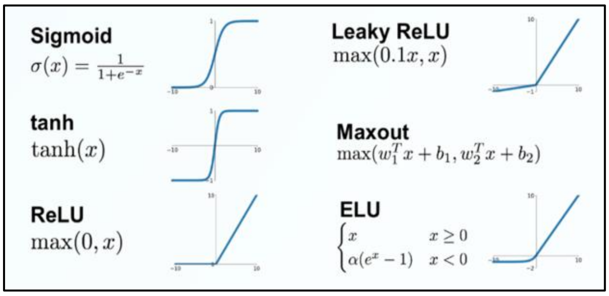
Yes, it looks quite complicated, but we'll go through it step by step.

On the very left, we have "a", this is what is output from neurons and it goes along the connection. The "a"s on the left are outputs from all of the neurons on the previous layer.

Each output goes into what's called a weight. The weight is a number that "a" is multiplied by and you can think of it as a measurement of how important that output is. For example, if identifying cats, it might be more important to look at the fur colour, then the shape of their head, and ignore the colour of the wall behind the cat; weights help to suppress unnecessary details and allow the more important previous nodes to have more influence.

These are all added together (that's what the **Σ** symbol means), alongside the bias. The bias is another number that instead represents how important a neuron is in the overall neural network, it may need to be increased so that the neuron isn't drowned out by less important neurons in it's layer, or decreased to suppress incredibly loud but unimportant or detrimental neurons.

After that, the current number goes into what's called an activation function. There are many kinds of activation functions and they all have different uses, but in general, they're used to stop values spiralling too positive or too negative. Here are a few:



There are of course more of them, including: parametric ReLU, GeLU, SiLU and more. But while their shape is quite important, it's not necessary to understand to fully to grasp neural networks.

Then, once the function outputs the final number, it's transferred as "a" to every other neuron in the next layer. And of course, this happens for every single neuron in that layer, and then the next layer; and in every single hidden layer until the output layer.

This means that there are billions of connections in the neural network. In fact, many neural networks are measured in parameter count, which is the total number of weights and biases in the model. Nowadays, 45b (45,000,000,000 parameter) models are the norm for running at home, but in servers, you can get up to trillions of parameters, which is a number growing with each innovation and breakthrough.

So in the end, what really happens in a neural network is you fill each input node with a number; and then eventually, at the end of it all, every output node will be filled with a different numbers. With all of that, it all feels quite lacklustre. It's just a whole load of maths.

But if you think about this a bit more; a whole load of maths can create so much and even save lives. Interesting, isn't it?

Dimensions and space time – by Elliot Voice

Spatial vs Temporal Dimensions

A dimension is an explanation in mathematics and physics, of how to describe positions, as well as measure them. Dimensions can also be used to describe movements as well as positions within our universe as a whole.

The Dimensions We Live In

In our current world there are four dimensions that we exist within. The three dimensions of Space. (Length, Height and Width) or in other terms (x, y, z). The other one dimension of Time. Together these four dimensions form the classical foundations of classical and relativistic physics. A spatial dimension is defined as a direction in space which an object can move or be measured along. Spatial dimensions are what build and define the shape and size of not just objects or our universe, but also the distance between these objects. In detail the three spatial dimensions that us humans can possibly perceive are these: The 1st dimension - A single line, A line with only length. No width & No height. The 2nd dimension - A plane or an area, A box as such, which can be seen with a length and a height, yet no forwards or backwards motion with width. The 3rd dimension - A volume, a complete three-dimensional space as we know it, and as we live in every day. A volume in which anything can move in an up & down, left & right, forwards & back motion. There are theories to suggest that there are higher dimensions such as 4D or 5D, yet they cannot be proven as of yet. Properties of these spatial dimensions are as such: Measured with length units, such as metres or km. Objects are able to move freely in any direction within the dimensional boundaries. These dimensions exist separately from motion and are always present no matter if something is moving or not.

What is spacetime?

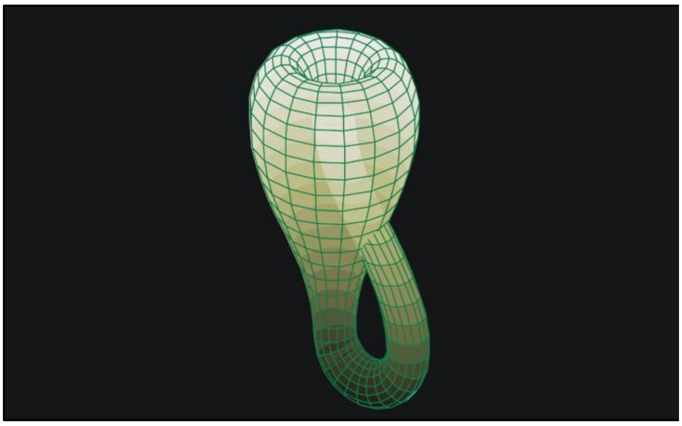
Spacetime is a four-dimensional mathematical model, that combines the three dimensions of space (Length, Height, Width) with the one dimension of time, into one four-dimensional construct. In the context of Special Relativity, time cannot be seen as a separate dimension from the three original dimensions of space. This is due to the observed rate of time passing depends on the objects velocity relative to the observer. As well as this, in the context of General Relativity, there is also an explanation for how time can be slowed for an object (seen by an observer outside the field) when this object is affected by a strong gravitational field. These two examples are known as Time Dilation.

Mathematical links to spacetime

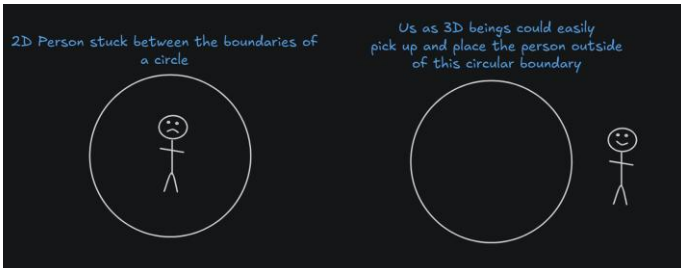
Mathematical events happen within a single point of space time, meaning they have a duration of zero. It is not possible for an Observer to be in motion relative to an event. Therefore, the path of an object/particle through spacetime is considered to be a sequence of events all connected, to form a curve to represent the object/particles progression through spacetime. Another thing is that spacetime is represented mathematically as a Manifold. Meaning that it appears locally "flat", when zoomed in on a small enough region. This is representative of the Earth, as from space it is viewed as a globe, however when standing on the Earth's surface at any point the world looks flat to humans. This principle is similar in spacetime, as it is curved by the presence of gravity, yet when examining a small enough region, it behaves like an ordinary flat space and time. This means that at any point in spacetime, local coordinates can be used, where the laws of physics resemble those of Special Relativity (Which assumes flat spacetime).

Can a 4th Spatial Dimension Exist

It is impossible to comprehend as 3 dimensional beings, how a fourth dimension would look. However, there are designs of objects that would work in a theorised fourth dimension. An example of one of these objects is the Klein Bottle.



Firstly, to understand this, I am going to explain this in the way that us (3D Entities) interact and abuse the physics of a 2D Entity/Object. Imagine a piece of paper in front of you, with a town full of people living on this piece of paper, with each person also two dimensional. Now as a three-dimensional being, we have the power to oversee the entire town from above corner to corner, yet the people living in this town would have to travel along this piece of paper from one corner to another to see each one separately. Another ability Humans would have over a 2D world, is the ability to reach into this Paper town anywhere and move any objects without breaking any physical boundaries. We could also move objects from one point to another just by picking it up and moving it, yet to the 2D beings in this town, the object would be viewed as just disappearing or teleporting.



Now if we think about these things by raising one dimension, a 4D entity could easily abuse our entire observable universe without breaking any physical boundaries. In the same way that we can see over walls in the 2D town, a 4D being would be able to see through enclosed objects, such as being able to interact with our organs and pull them out of our bodies, but to us this would just look like our organs teleported away.

Can We Travel into Higher Dimensions:

While it seems theoretically possible for humans to travel into a fourth dimension, it is not exactly understood. It is believed that a range of effects could happen to our bodies if we were to travel into it.