What is the 4th dimension?

By Chloe Rigby

Introduction:

Have you ever wondered why our eyes are restricted to the 3rd dimension? What actually is the 4th dimension itself? Theoretically, there are at least 10 proposed dimensions, however the human eye is only bound to two. But why is this so?

How dimensions work:

There are 3 visualised spatial dimensions: length, width and height. These are also known as (x, y, z) in Cartesian form. Each of these variables correspond to the 3 dimensions we experience – x relates to a single line (1D), x and y are perceived by flat surfaces, or graphs and x, y, z are the axes humans see in. Take a block of wood, for example, it has length, width and height, just like the coordinates x, y, z on a graph do. Ultimately, this reinforces that everything we see can be described by these dimensions within mathematics. So essentially, dimensions are just directions and our brains fill in the rest.

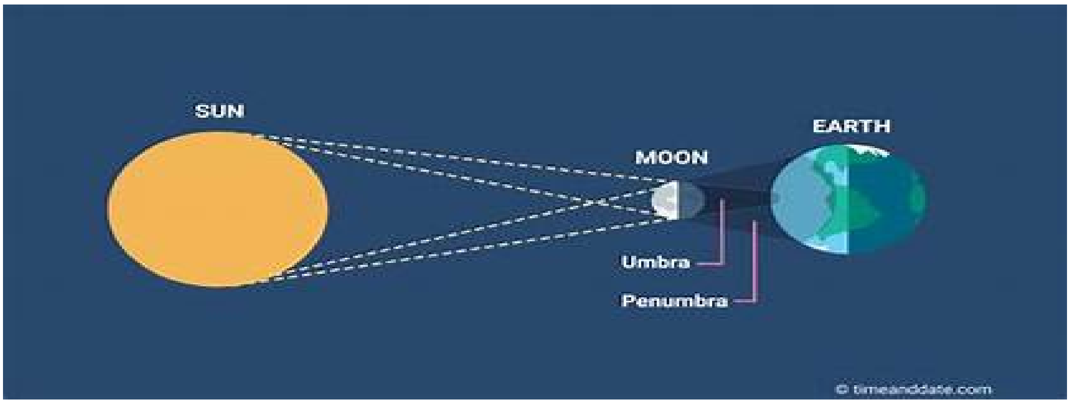
The brain:

Everything the human eye sees is light; without it we only see darkness, which is what shadows are. When light enters the lens through the pupil, it is refracted to form a virtual image on the retina, meaning the image is inverted and in 2D. Through the optic nerve, electrical impulses are sent to the visual cortex. This is where the brain flips the image, adding depth and definition. This is the process that allows us to see reality. Neat! This is very similar to how computer graphics render 3D scenes into 2D images. The object begins as 3D, with x, y and z coordinates acting as vertices that connect to form virtual triangles, which add texture and depth to the image. Computers rasterize the virtual object into pixels (dots) onto a 2D screen [1], which is then buffed out to apply more texture and light to the pixels, creating the illusion of depth and definition. This process can be magnified to large scales, as seen on televisions. On the other hand, when our brains receive the 2D image, the visual cortex processes the image, inverting it from pixel form to a detailed and clear image, creating reality as we know it. Furthermore, each eye perceives the world at a slightly different angle along the horizontal plane, nevertheless each image seen is still in 3D. This raises the question whether our brains are truly capable of seeing in the 4th dimension…

Why do we only see in 3D?

Every image processed by our brains is 3D, even those seen on a flat screen. For example, when you watch your favourite series on a computer screen, the people and objects perceived are 3D – they have definition, texture and depth, as well as direction. However the screen itself is flat, so we still see it in the 3rd dimension. As I touched on earlier, the shadows surrounding an image, both virtually on a screen or in real life, are simply an absence of light. But they add contrast to the object, so some would argue this is an example of the 2nd dimension. Technically, this is true as shadows only show length and width, however a silhouette can be elongated by a fluid (such as water or fog), causing light to scatter and refract, appearing as a 3D object. Therefore, it is reasonable to say that the human eye can also experience the 2nd dimension in a 3D matrix.

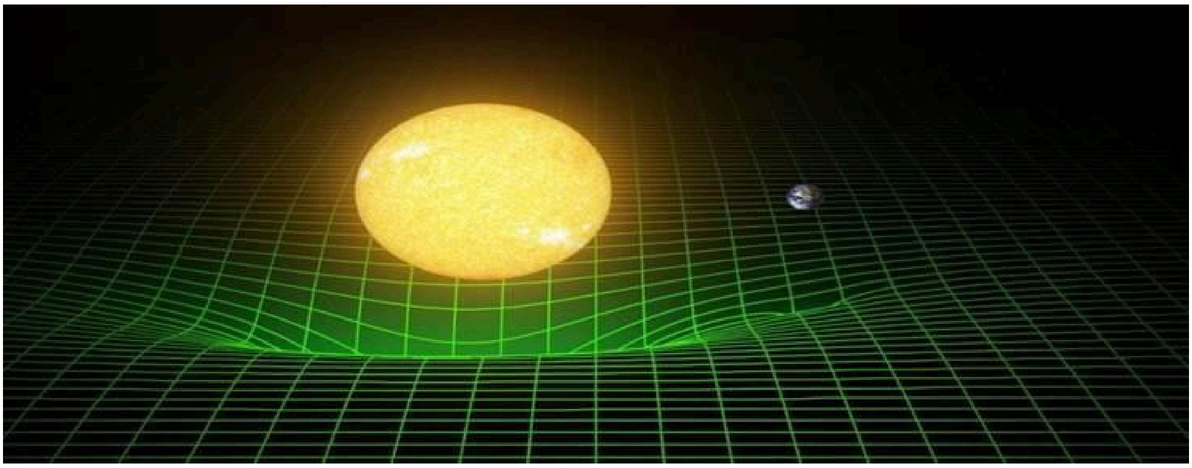
When a point source of light hits an object (in this instance, the object is opaque), a dark 2-dimensional shadow is cast from the cover of the object: this is called an umbra.



Celestial bodies are a classic example of how the human perception of the 2nd dimension is applied into reality. As the Moon blocks the Sun during a total solar eclipse, an umbra is cast onto a specific area on Earth, creating a 2D shadow on a large-scale. However, the umbra actually has a volume from the cone-shaped shadow cast by the Moon, meaning that the 3rd dimension is still present, and the shadow only appears as 2-dimensional when the umbra's volume intersects with the Earth. Additionally, a penumbra is the region where a light source is partially blocked by the object, creating soft edges to the shadow. [2] A penumbra is an example of a 3D shadow, as the silhouette's volume extends through space, giving it length, width and height. Hence, the human eye can perceive the 2nd dimension, but in reality, the 3rd dimension is omnipresent.

The fourth dimension:

Now is the time to mention what the fourth dimension really involves. According to Albert Einstein, the 4th dimension is time; it is another independent spatial direction, just like the x, y, z axes, however the human eye struggles to perceive this. A 4D object can be described as an extension of a 3D space – as seen with 4-dimensional shapes holding 3D shadows. Confusing, right? How can a scalar quantity of time also be an extension of a dimension?



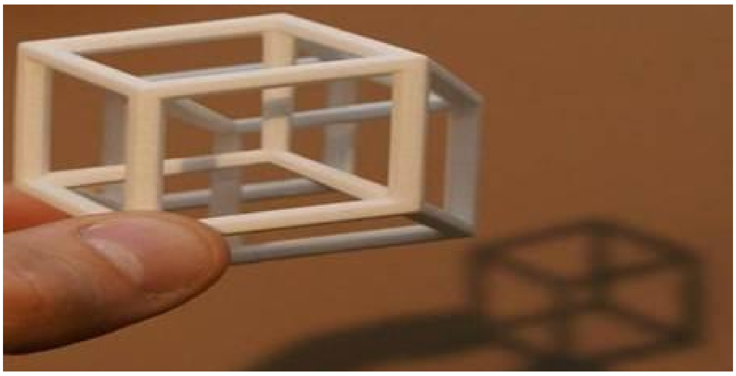
Well, within physics this is possible, as seen in Albert Einstein's General Relativity: gravitational time dilation is a consequence of general relativity [3]. This means that clocks run slower in deeper gravitational wells, therefore time is affected by gravity itself. Consequently, you can think of time behaving like the structure of space to allow it to be classed a separate dimension. Furthermore, the fact that time can be compressed and altered by gravity highlights that time can move in a direction, just like another dimension.

The 4th dimension in mathematics:

Mathematically, the Euclidean distance formula: $d = \sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2]}$ can be used to calculate the distance between 3 points in the x, y, z axes. Each set of points (e.g. x_1 and x_2) are coordinates in a 3-dimensional plane [4]. This formula is the laying foundation for Minkowski spacetime, where space and time are a unified structure, involving coordinates (x, y, z, t) with t representing the 4th dimension. The Euclidean distance formula can be rewritten as $d^2 = x^2 + y^2 + z^2$ which relates to the special relativity formula: $s^2 = x^2 + y^2 + z^2 - c^2t^2$. It is worth noting that the first part of this formula is the same as the Euclidean distance formula, except the time dimension takes a negative value [5], therefore as time and space share the same structure [6] under Minkowski spacetime, the 4th dimension is present within distances of our own universe and can be measured as a quantity.

4D in practice:

Practically, it is very difficult to picture a quantifiable image of a 4D image. As I talked about earlier, mathematically, the 4th dimension can be represented through time, as well as a direction, however this doesn't apply physically as time is not physical. Tangibly, a tesseract is a 4-dimensional hypercube involving a 2D square and a 3D cube. The hypersurface of a tesseract has 8 cells that meet at right angles to one another [7]. This shape combines the 2nd and 3rd dimension to help visualise the 4th dimension. Evidently, this is seen when a tesseract casts a shadow; a 3D cube appears, similar to how a 3-dimensional object casts a 2-dimensional shadow, a 4D object creates a 3D shadow.



This is a beautiful representation as to how an optical illusion can give us an insight into another dimension. Furthermore, the 4th dimension can be seen through CAT scans. For example, the technique of four-dimensional computed tomography (4DCT) uses x-rays to locate specific glands within the neck. This process functions by taking 3D images of the gland, over a period of time, which creates a moving image of the glands, almost like a video. Physiological movement is recorded, acting as a direction within the 3rd dimension. Layers of these observations, from images continually being captured by the scanner, form another direction, ultimately creating another dimension. The images are sorted into phases of motion, contributing to the representation of the 4th dimension.

Conclusion:

In closing, I hope this essay has given an insight to the 4th dimension and how it can be applied to reality. Any dimension, other than the ones we know of, are hard to visualise, so the 4th dimension is best perceived as a direction, similar to the 3D graphs. Crucially, shadows can give accurate representations of how 4D shapes link to our own dimension. Through the collaboration of the physics behind relativity and the mathematics of geometry, the 4th dimension can be accurately measured, quantifying something eternal and transient. Ultimately, the 4th dimension is omnipresent, directional and now easier to understand!

References:

[1] - https://blogs.nvidia.com/blog/whats-difference-between-ray-tracing-rasterization/

[2] – https://en.wikipedia.org/wiki/Umbra,_penumbra_and_antumbra

[3] - https://en.wikipedia.org/wiki/Theory_of_relativity

[4] - https://www.cuemath.com/euclidean-distance-formula/

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[6] - https://en.wikipedia.org/wiki/Minkowski_space

[7] - https://en.wikipedia.org/wiki/Tesseract