THE SHAPES OF OUR WORLD

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Intro: A Not So Simple Question

"What shape is the world?"

It sounds like the kind of question that has an easy-going one-word answer. A sphere, maybe, or a cube, maybe even a triangular prism if you're in a good mood. It should be something neat, something you could draw in a few seconds and move on from.

But that answer only works if you don't look past the tip of the iceberg.

The moment you dive deeper, the world stops behaving like a clean diagram. Instead, it branches, cracks, curves, and stretches. Even the idea of "shape" starts to change depending on what you are looking at.

So instead of lazily giving one answer, I'll follow the question through different scales, with each increment resulting in varying mathematics. After all, our world has so many things to explore.

1. The Decimal World Of Ever-growing Fractals

A good place to start is with a topic that appears everywhere we look, ***Fractals***: complex shapes and patterns that vary and change as you peer into them.

Take something like a branching pattern. Blood vessels, lungs, lightning, cracked glass. They all share the same structure: one line splits into two, which split again, and again. You could zoom in and still recognise the pattern.

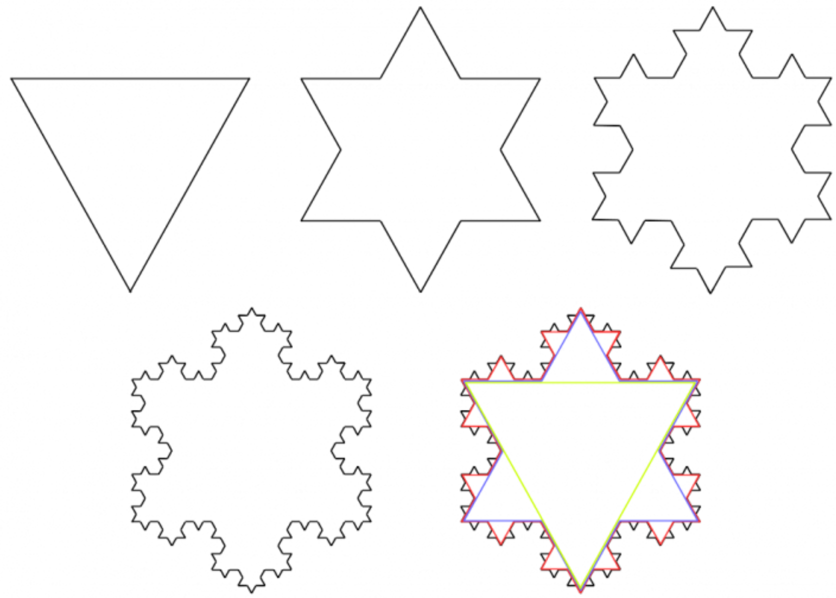
This idea is called self-similarity, and it leads to fractals.

The interesting part is not just how they look, but how they scale. Suppose a shape is made from N smaller copies of itself, each scaled down by a factor of r. Then its dimension is given by

$$D = \frac{\log N}{\log\left(\frac{1}{r}\right)}$$

This isn't the type of dimension that you would usually think of, but rather a more mathematical definition of how much space is filled as a shape scales, called the ***Haursdorff dimension***

As an example, take the Koch curve. Each line is replaced by 4 smaller lines, each one third of the size of the original line.



Substituting $N=4, r = 1/3$:

$$D = \frac{\log 4}{\log 3} \approx 1.26$$

According to that number, the Koch Curve shape lies roughly in the 1.26th dimension, meaning it has an infinite length but occupies a finite area, making it a "curve" that is more than one-dimensional but not covering its entire closure, so it regrettably doesn't make the cut to be a surfaced 2D shape.

A more practical way to model a fractal is to ask: how does the amount of detail change as you zoom in? This is captured by the relation:

$$N(r) \propto r^D$$

If D is larger, the structure fills space more efficiently. For example, if you double the scale and the number of branches more than doubles, then the structure is spreading faster than a simple line would, which is exactly what is needed in lungs or blood vessels or any other occurrence of fractals in nature. You want as much coverage as possible without increasing the volume, be it for transfers of particles in the body, or the transfer of energy in lightning or glass.

2. When A Sphere Just Isn't Enough For Planet Earth

After exploring fractals, it's quite tempting to return to more simple shapes, which one would assume the Earth is. But while it's extremely smooth (to the point that it would outshine a billiard ball), it's shape resembles less of a sphere, and more of an apple from an extremely poor harvest. It is an ***Oblate Spheroid.***

Because the Earth rotates, it bulges at the equator. So instead of a sphere, we get an oblate spheroid. In cross-section, this is an ellipse:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

When $a = b$, this equation reduces to a circle, but in Earth's case, $a > b$, resulting in an equator slightly larger than its pole-to-pole distance. We can measure this difference while also calculating how flat the Earth is through:

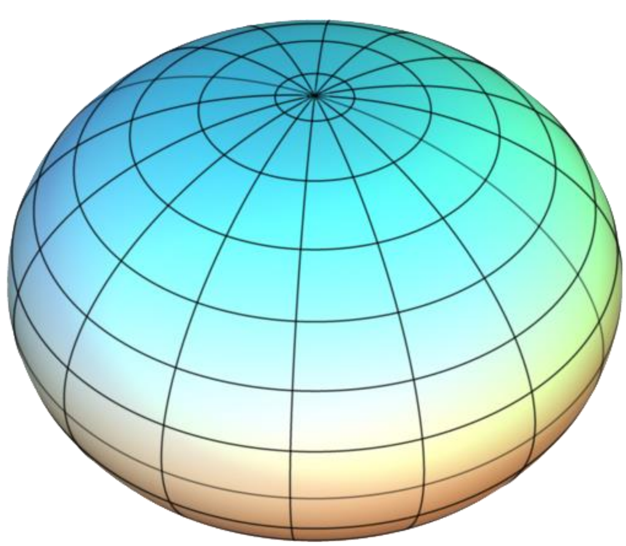
$$f = \frac{a - b}{a}$$

If $f = 0$, the shape is fully spherical. But for Earth, with Equatorial radius $a \approx 6378.14\ km$, and the Polar radius $b \approx 6356.75\ km$, we get:

$$f = \frac{(6378.14 - 6356.75)}{6378.14} \approx \frac{1}{298}$$

This may not seem like an impactful flattening value, but on a large scale like Earth's, it results in a vastly different shape. The key idea here is different from fractals: There is no repetition, Instead, the focus is on approximation. A sphere is close to Earth's shape, but not exact, and mathematics gives us a better model to represent this.

An oblate spheroid



3. The Eccentric Curves Of Space

Up to this point, we have been discussing shapes existing inside and covering space, but what about the shape of space itself?

In geometry, the angles in a triangle, say, α, β, and γ add up to $180°$, and for the majority of people, this is where they conclude, since Euclid's theorem seems absolute enough.

Rather on the contrary, this only applies to flat geometries. If we draw a triangle onto the surface of, say, a sphere, it can be observed that the sum of the angles has become greater than $180°$.

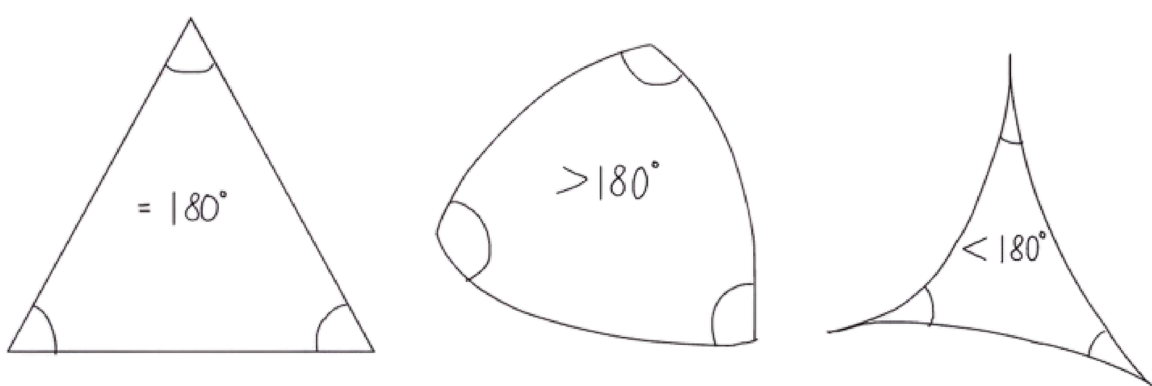
This type of geometry which doesn't obey Euclid's geometry, is creatively called ***non-Euclidian geometry***

The main 3 ideas of curvature can be summarised by:

$$K = 0,\ K > 0,\ K < 0$$

Where K simply refers to the curvature of a shape or line, and:

$K = 0$	Flat geometry which follows Euclid's postulates
$K > 0$	Spherical geometry where angles added up are greater than 180°
$K < 0$	Hyperbolic geometry where angles added up are less than 180°



Since it can be understood from a physical perspective that the space in the universe is *not* flat as a result of the effects of gravity curving space, it can be stated that the space that we occupy in the universe is non-Euclidian, which may be hard to visualise though it's the truth.

On an even grander scale, it can be said that the universe itself possesses a non-Euclidian structure. And though we have discussed several shapes present in our world, a question can still be raised:

"What shape is our *literal* world?"

4. Analysing the Cosmos : The Grandest Scale of Shapes

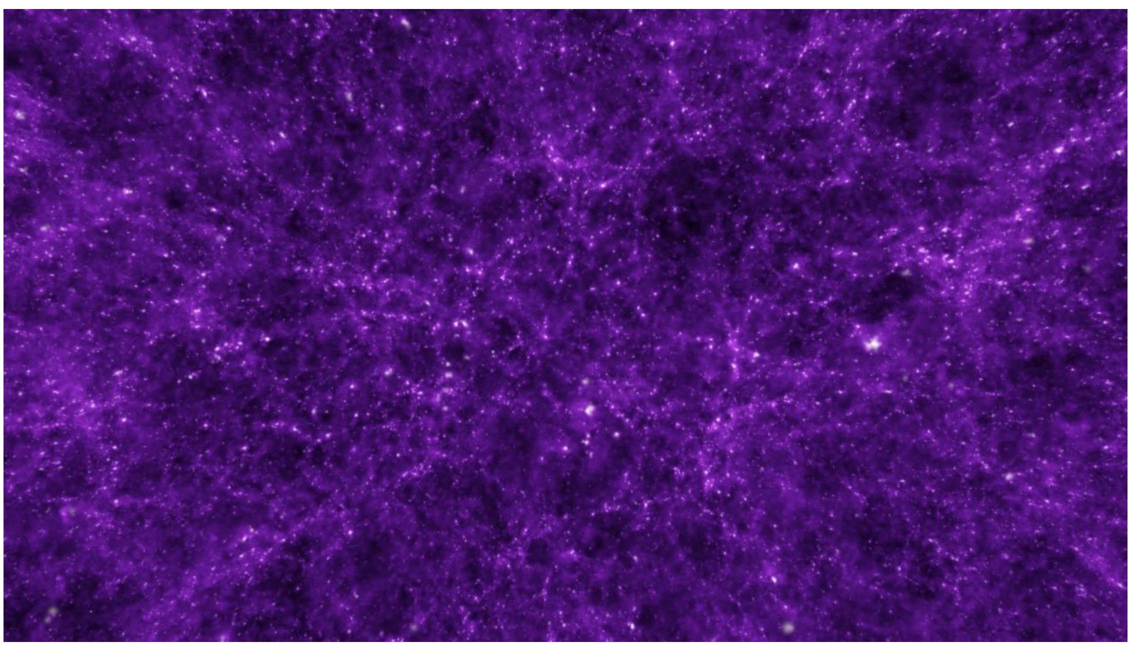
Though we cannot exactly pinpoint the shape of our universe, we can still analyse and model the cosmos to get a rough idea. At this point, the question is warped into how matter is distributed.

First, it must be understood that galaxies are not evenly spread out, but rather, they form clusters, which are connected by long filaments, with large empty regions in between. This structure is known as the cosmic web.

A rather interesting observation is that even this cosmic web possesses fractal traits, in that each strand of billions of galaxies branches out into further, thinner strands. It is not the same as branching in lungs or glass, but there is still a sense of repeated structure:

Matter seems to organise itself into connected patterns rather than filling space randomly, as if it is trying to optimise its path.

The cosmic web and its fractal nature - NASA



One way to model the cosmic web, though it hangs on the precipice between mathematics and physics, is through density:

$$\rho(r) = \frac{M(r)}{V(r)}$$

This measures how much mass is contained within a region of size r .

Another complementary idea is counting how many galaxies lie within a certain distance:

$$N(r) \propto r^D$$

Where D is a chosen distance and r is still a region of size.
A method to convert this relation to be represented as a graph is through converting the relation into an equation, and then taking logarithms:

$$\log\big(N(r)\big) = \log(r^D)$$

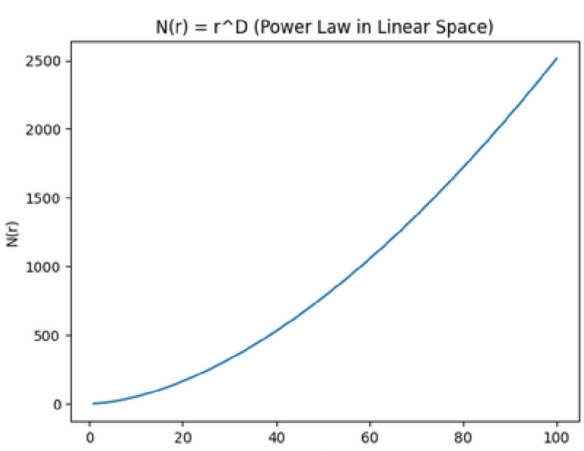
And through log laws:

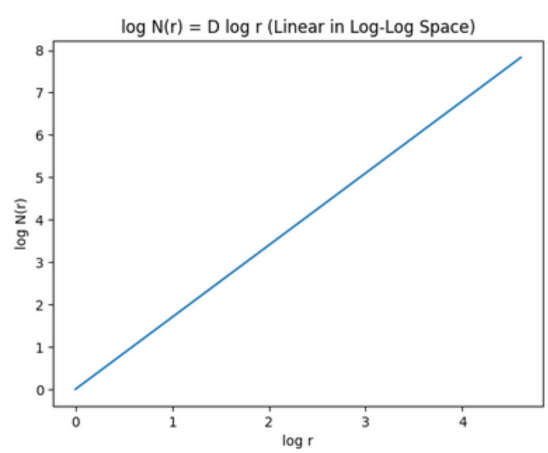
$$\log\big(N(r)\big) = D\log(r)$$

We now have an equation which is an identity of $y = mx$. This is useful because it turns the relationship into a straight line on a graph, where the gradient of that line gives information about how clustered the galaxies are.

If doubling r leads to much more than double the number of galaxies in the exponential relationship, then matter is strongly clustered. Through logarithms, it scales more evenly, resulting in a smoother, easier to observe distribution.

Though this section was less about shapes, and more about structures, it still shows how mathematics can be present at any scale, helping to find patterns that would otherwise be too large to see directly.





5. Conclusions: The Ever-Morphing Nature

After reading this essay, we can conclude that the shape of the world is not a single entity or object that can be completely drawn and labelled, like typical shapes;

At small scales, branching patterns lead to fractals and confusing non-integer dimensions, At planetary scales, familiar shapes like spheres turn out to be approximations, At even larger scales, geometry itself depends on curvature - causing our question to slowly deteriorate, And at the largest scales, the question entirely shifts from shape to distribution.

One thing we've learnt and can finalise an opinion on is that, at every different scale, and at every varying topic in our world, mathematics is always present. And it is this presence of mathematics everywhere we look that causes confusion for the initial question; The world doesn't have a single shape, but rather many different ones. You could say that mathematics is the magnifying glass needed to observe each shape.

In the end, the world is a non-linear progression, where each branch expands into further objects to explore, kind of like a fractal.