



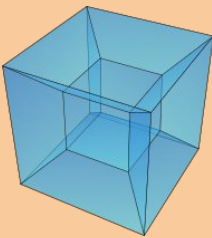
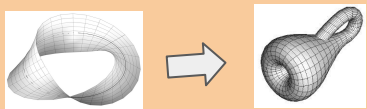
# The Fourth Dimension and Beyond!

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 2020 GSSE Mathematics Class  
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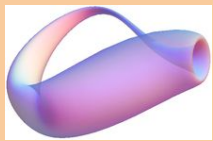
## Famous 4D Shapes

Some of the most studied four-dimensional shapes are hypercubes, hyperspheres, and Klein Bottles.

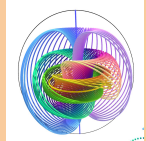


Hypercube visualization in 2D

A Klein Bottle is a 4D representation of the famous Möbius Strip, resulting in a never-ending bottle with its outside flowing into its inside without breaking the walls.



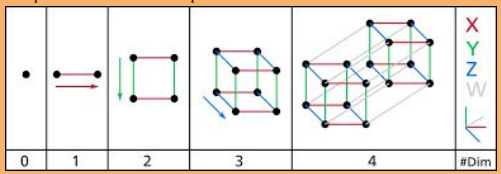
Hypercubes and hyperspheres are exactly what they sound like: four-dimensional versions of cubes and spheres, obtained by lifting these shapes in the fourth dimension.



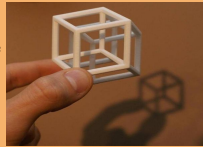
Hypersphere visualization in 2D

## The 4th Dimension

We use dimensions to describe the world around us. Each new dimension expands from the previous ones in a new spatial direction.



The 4th dimension of space is an extension of the 3rd dimension. For example, we can expand a simple square from the 1st dimension to the 2nd, and on to the 4th dimension (above). Since our vision can only process up to three dimensions, we cannot see or truly picture a 4D object, but we know that the shadow of such an object would be three-dimensional.



## String Theory

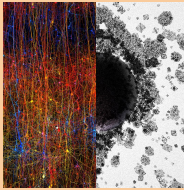
The string particle still has all the same properties as the particle, but the string's frequency, or how the string is vibrating, determines all the properties of the particle. These strings are used to understand different fundamental aspects on the quantum scale.

Another aspect of the 4th dimension is the concept of string theory. In string theory, all particles, which are considered single points in space, are changed into a one-dimensional shape: a string!



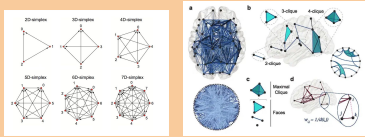
String theory doesn't just help give meaning to the 4th dimension, it helps us give meaning to all dimensions up to the 10th! In order for this theory to work, scientists had to conceptualize six further and deeper dimensions.

## Neuroscience in Multiple Dimensions



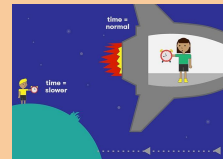
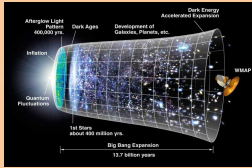
Our brain is capable of working in 11 dimensions. When working on a problem, our brain forms multi-dimensional structures using neurons. While other organs in the body work in four dimensions (three being spatial and fourth being time), our brain routinely works with 7 and even 11 dimensional structures. By working on a difficult problem, our body stimulates the brain which causes cliques or sets of neuron structures to form.

Researchers started using algebraic topology in order to detect and visualize these multi-dimensional structures. Algebraic topology is able to describe systems with any number of dimensions.



## The Space Time Continuum

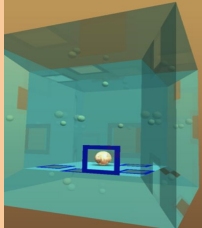
In the study of the universe, it is convenient to think of time as the 4th dimension. Time is portrayed as one continuum with the past, present, and future existing all at once. The "present" time is one slice of the whole continuum, and all these subsequent slices are spliced together to create the history of the universe.



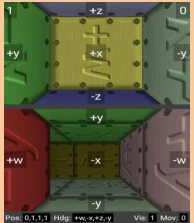
The notion of Space-Time can explain very strange phenomena such as Gravity Time Dilation. Observers situated at different distances from a gravitational mass will perceive time passing at different speeds. Time runs slower where gravity is strongest. Thus, gravity distorts the normal flow of time and affects the time dimension.

## 4D Video Games

Popular examples of 4D video games include Miegakure, HyperMaze, and Tesseract. These games utilize the 4th dimension in various unique ways. For example, both Miegakure and HyperMaze take a three dimensional game and add one more dimension of space that you can view and travel through, to experience four dimensions.



Tesseract (shown above) is similar, except instead of being able to see a 4th dimension, gravity is altered to simulate how an added dimension would impact the other three.



"No one can point to the fourth dimension, yet it is all around us"  
 - Rudy Rucker, Mathematician and Sci-Fi Author

