Conceptualizing Other Dimensions

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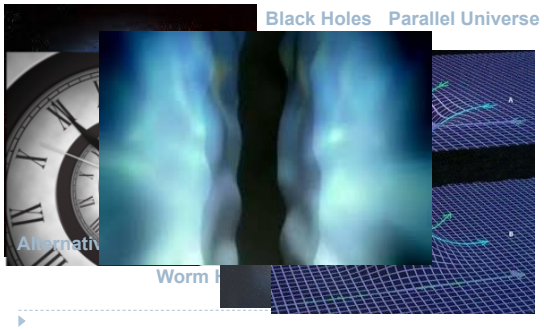
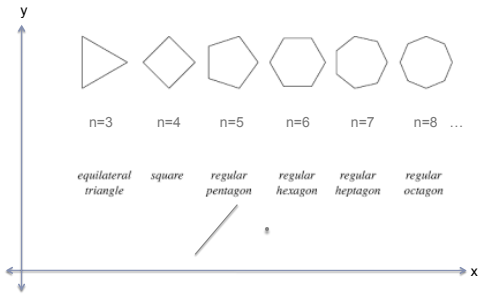
What Do We Mean by Other Dimensions?

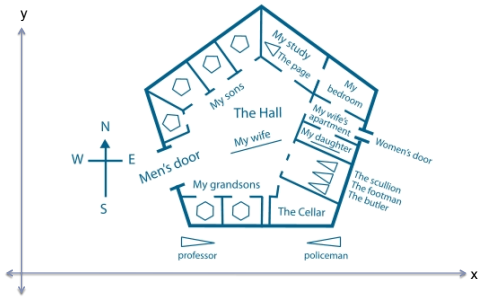


2-Dimensional Tale

2-Dimensional Polygons

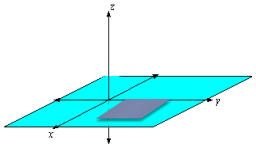


2-Dimensional Motion



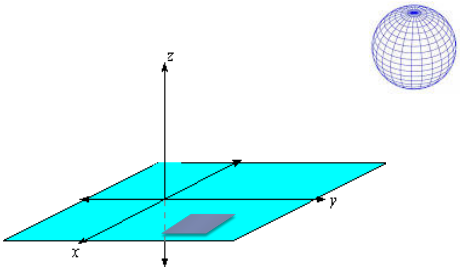
- Mr. Square

- The Plane

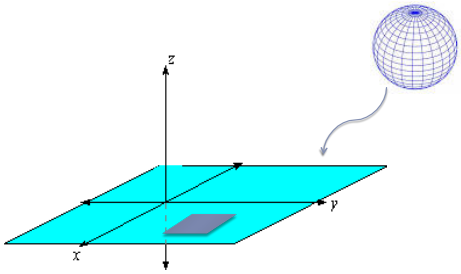


A Visitor From Another Dimension

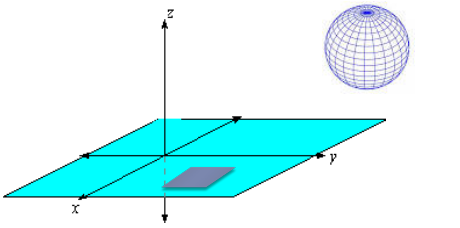
- Madam Sphere



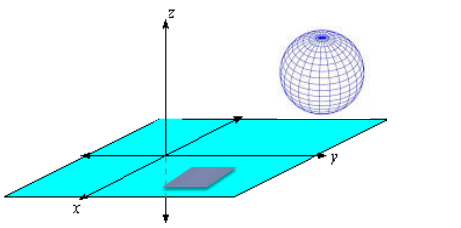
- Madam Sphere



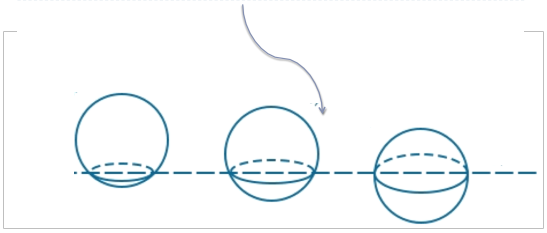
- Madam Sphere



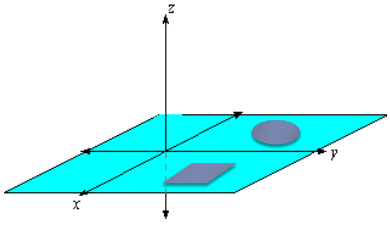
- Madam Sphere

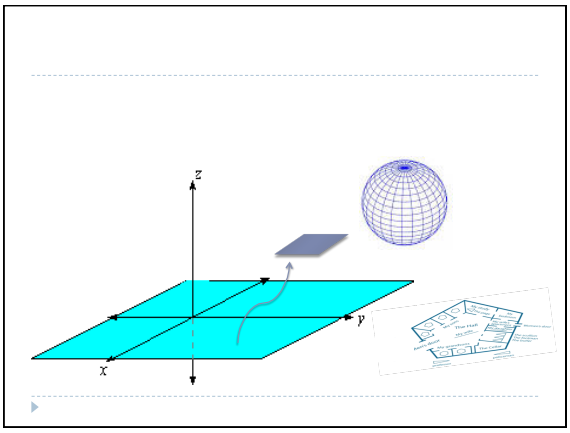


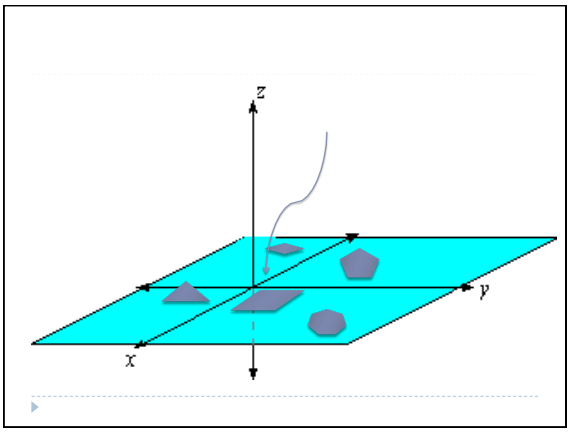
Transition into the Plane



Cross Sections Seem to Appear.

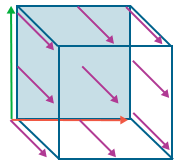






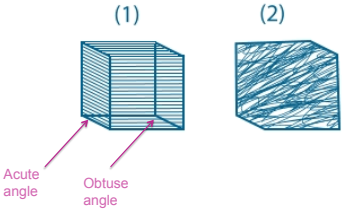
Extending into a 3rd dimension

2-D into 3-D

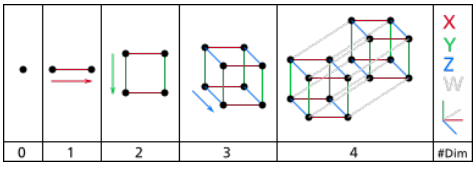


3 dimensional figure imposed on a 2 dimensional space.

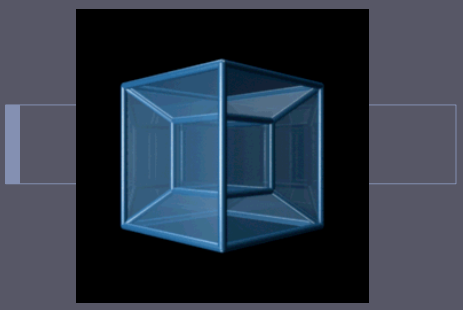
A shadow of a cube



Extending into Larger Dimensions



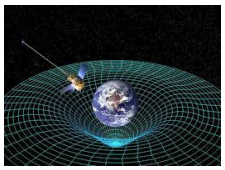
Tesseract



Look in Rather than Out

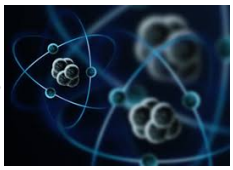
Relativity

Explains the Large



Quantum

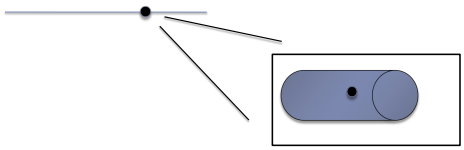
Explains the Small



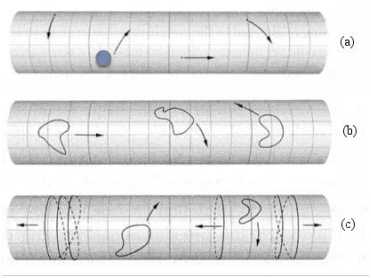
Smaller Dimensions

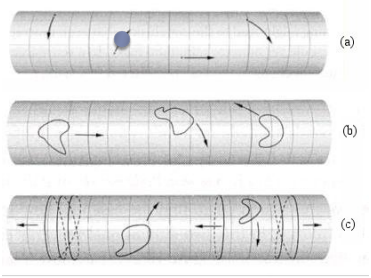
A line segment

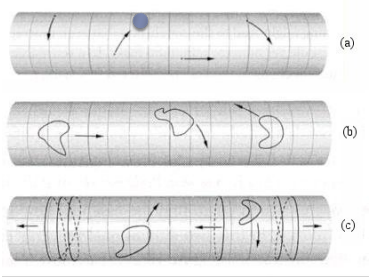
- Zooming in we see thickness

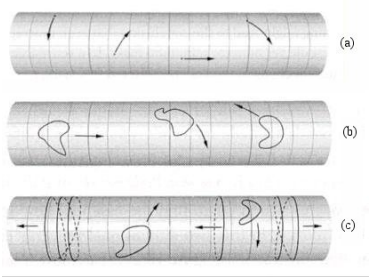


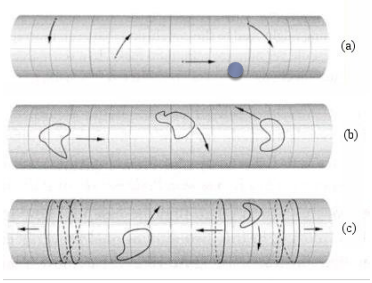
Wrap Around Intertwined Dimensions



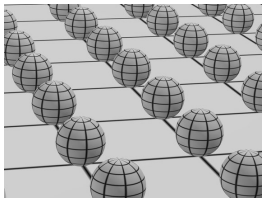








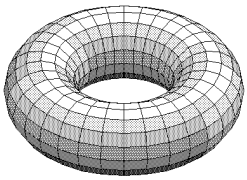
Multiple Spatial Dimensions



- At every point in space there are extra spatial dimensions that wrap around.

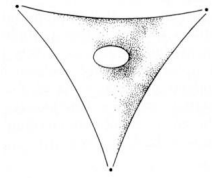
Some Topology

Torus



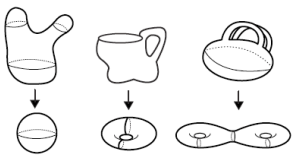
- If torus are mapped into one another (by rotating 2/3), it is possible to generate a orbifold.

Orbifold



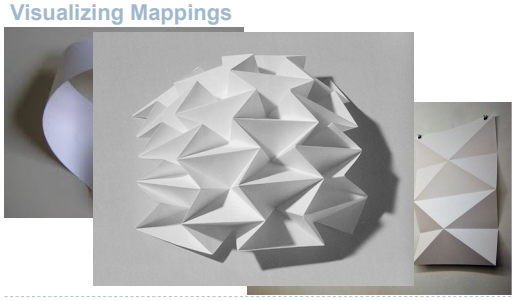
- Combining three such orbifolds together, it is possible to generate a six-dimensional space with 3 X 3 X 3 = 27 singular points

Topologically Equivalent

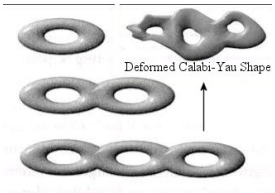


- Properties are preserved through deformations, twisting, and stretching of objects.
- Tearing, however, is not allowed.

Visualizing Mappings



Calabi-Yau Shape

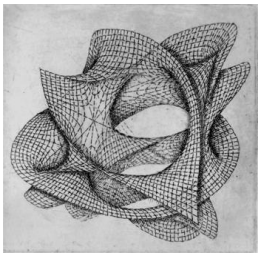


- Calabi-Yau shape can be deformed in many ways, there are literally an infinite variety of them.

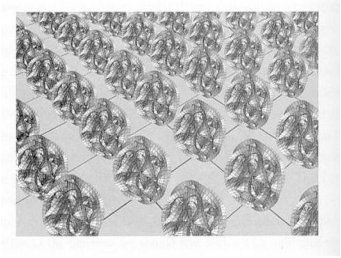
6 Dimensional Figure

- However, the formulation is not on a truly manifold because it involves singular points.

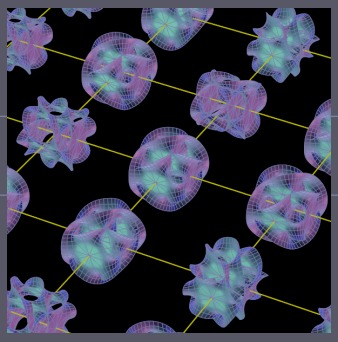
Calabi-Yau Manifold



9 – Spatial Dimensions.



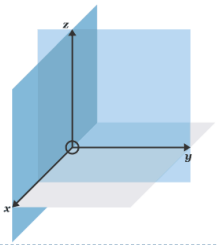
Calabi-Yau Manifold



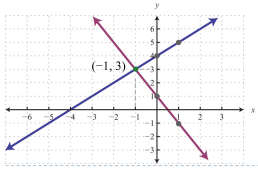
Some Mathematics.

x+1=10

ax + by + cz = d



y=mx+b



String Theory

$$H\Psi = i\hbar\frac{\partial\Psi}{\partial t},$$ Schrodinger Equation

$$H = -\frac{\hbar^2}{2m}(\nabla^2_{x_1} + \nabla^2_{x_2} + \ldots + \nabla^2_{x_N}) + V(x_1, x_2, \ldots x_N)$$

- String Particles
  - Wave functions
    - Multiple Degrees of Freedom
      - Complex Vector Space
        - Metric Space
          - Hilbert Space

Function Mapping

- Classically a particle can go in a time t from point a to point b along some path.

- Quantum mechanically we instead have a linear evolution operator.

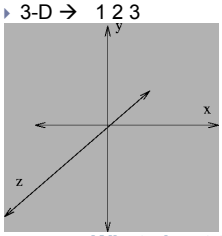
$$\Phi_t = H \rightarrow H$$

Mapping involves time

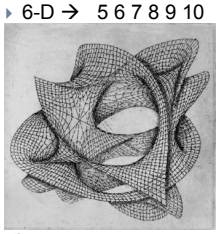
11 – Dimensions of String Theory.

Spatial dimensions

- 3-D → 1 2 3

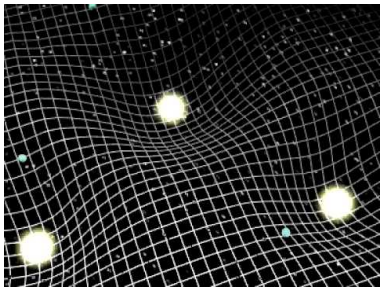


- 6-D → 5 6 7 8 9 10



What about the 4th dimension?

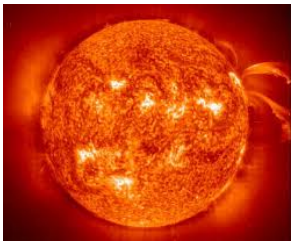
Time as a Forth Dimension (x , y , z, t)



Time Has Length

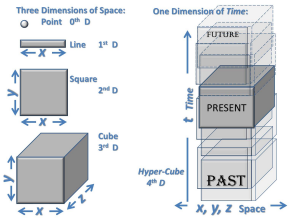
Human length: 80 years

Star length 10 billion years

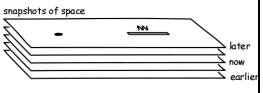


Space as a Plane

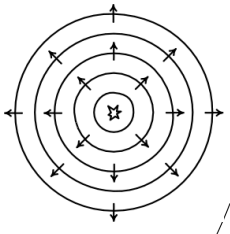
Space as 3-D



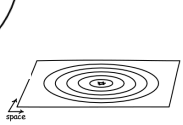
Space as 2-D

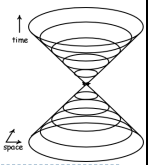


Light Source Moving in Time

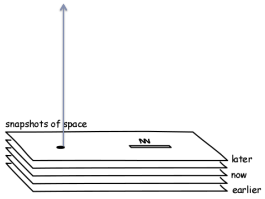


Creates a cone from present time.

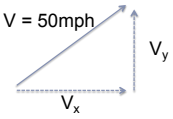




Distribution of Speed Between Dimensions

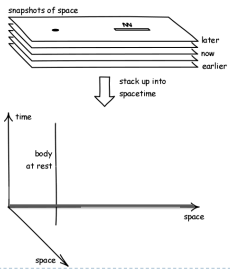


Maximum speed through time is the speed of light.

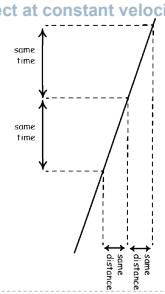


Motion Through Time

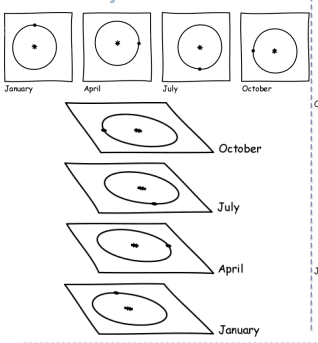
Object at rest



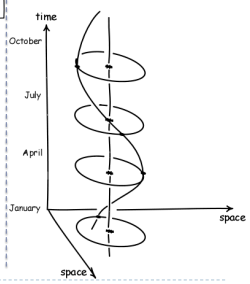
Object at constant velocity



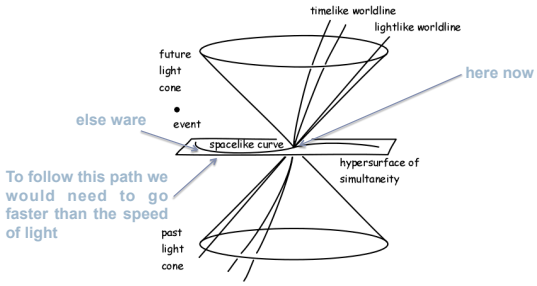
Object in motion



Timelike worldline

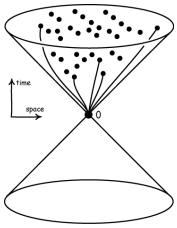


2 – Dimensional Light Cone.

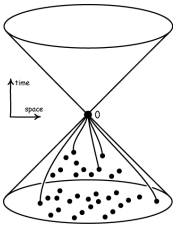


Events in Spacetime

Light cone of future events

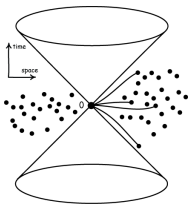


Light cone of past events



Minkowski Spacetime

Light cone of events elseware



- The remaining region of the spacetime is outside both past and future light cones.
- It collects all events that cannot be connected to event O by timelike or lightlike curves. Its events can only be connected to O by spacelike curves

The 11th Dimension

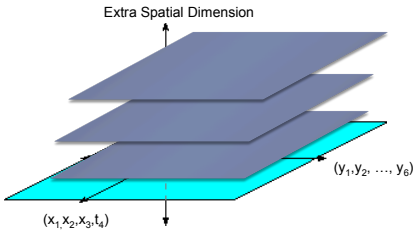
Spatial Dimension

- Mathematical equations require string particles to move with 11 degrees of freedom.

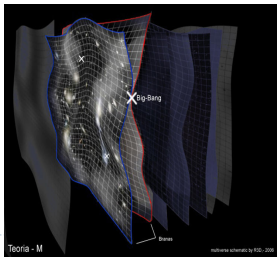
Extremely large

- If there is enough energy objects in this extra spatial dimension can grow as large as the universe.

Branes



Possibility of Multiple Universes



Reference Links

- **"The Mathematics of M Theory" Robbert Dijkgraaf**
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- **"Spacetime" John D. Norton**
  - http://www.pitt.edu/~jdnorton/teaching/HPS_0410/chapters/spacetime/
- **"The Elegant Universe" Brian Greene, Text:**
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  - https://www.youtube.com/watch?v=H2MpJVw8A3s
- **"Flatland" Edwin A. Abbott**
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- **Superstring Theory**
  - https://universe-review.ca/R15-18-string03.htm

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Q & A