8.286 Lecture 11
October 17, 2013

NON-EUCLIDEAN SPACES: CLOSED UNIVERSES
REVIEW OF LECTURE 10:

INTRODUCTION TO NON-EUCLIDEAN SPACES
curved space?

curved spacetime?

curves with respect to what?

non-Euclidean geometry

Note on image: I have added the “Dali” clock and Fermi satellite images to the original image created for the Gravity Probe B collaboration.
Euclid’s Postulates

1. A straight line segment can be drawn joining any two points.
2. Any straight line segment can be extended indefinitely in a straight line.
3. Given a straight line segment, a circle can be drawn having the segment as radius and one endpoint as center.
4. All right angles are congruent.
5. If a straight line falling on two straight lines makes the interior angles on the same side less than two right angles, the two straight lines if produced indefinitely meet on that side on which the angles are less than two right angles.

Corrected 10/10/13
5. If a straight line falling on two straight lines makes the interior angles on the same side less than two right angles, the two straight lines if produced indefinitely meet on that side on which the angles are less than two right angles.
(a) “If a straight line intersects one of two parallels (i.e., lines which do not intersect however far they are extended), it will intersect the other also.”
(b) “There is one and only one line that passes through any given point and is parallel to a given line.”
(c) “Given any figure there exists a figure, similar to it, of any size.” (Two polygons are similar if their corresponding angles are equal, and their corresponding sides are proportional.)
(d) “There is a triangle in which the sum of the three angles is equal to two right angles (i.e., 180°).”
Giovanni Geralamo Saccheri (1667–1733)

In 1733, Saccheri, a Jesuit priest, published *Euclides ab omni naevo vindicatus* (*Euclid Freed of Every Flaw*).

The book was a study of what geometry would be like if the 5th postulate were false.

He hoped to find an inconsistency, but failed.
German mathematician and physicist.

Born as the son of a poor working-class parents. His mother was illiterate and never even recorded the date of his birth.

His students included Richard Dedekind, Bernhard Riemann, Peter Gustav Lejeune Dirichlet, Gustav Kirchhoff, and August Ferinand Möbius.
~1750-1850

- infinite
- constant negative curvature

5th Postulate

\[ a + b + c < \pi! \]

Slide created by Mustafa Amin
GBL geometry with Klein

1. constant negative curvature
2. infinite
3. 5th postulate

\[(x_1, y_1)\]

\[x^2 + y^2 < 1\]

\[(x_2, y_2)\]

\[d(1, 2) = \cosh^{-1} \left[ \frac{1 - x_1x_2 - y_1y_2}{\sqrt{1 - x_1^2 - y_1^2} \sqrt{1 - x_2^2 - y_2^2}} \right]\]

Note: no global embedding in 3D Euclidean space possible
Geometry (after Klein)

co-ordinates

\((x_1, y_1)\)

\((x_2, y_2)\)

distance function

\[d[(x_1, y_1), (x_2, y_2)]\]
tiny distances

ds^2 = dx^2 + dy^2

ds^2 = g_{xx}(x, y) dx^2 + 2g_{xy}(x, y) dx dy + g_{yy}(x, y) dy^2
quadratic form

\[ ds^2 = g_{xx}(x, y)\, dx^2 + 2g_{xy}(x, y)\, dx\, dy + g_{yy}(x, y)\, dy^2 \]
locally Euclidean

\[ ds^2 = dx'^2 + dy'^2 \]

\[ ds^2 = g_{xx}(x, y) dx^2 + 2g_{xy}(x, y) dx dy + g_{yy}(x, y) dy^2 \]

\[ g_{xx}g_{yy} - g_{xy}^2 > 0 \]
Non-Euclidean Geometry: The Surface of a Sphere

\[ x^2 + y^2 + z^2 = R^2. \]
Polar Coordinates:
Varying $\theta$: \[
\begin{align*}
\theta &\quad \text{(angle)} \\
R &\quad \text{(radius)} \\
d\theta &\quad \text{(differential)}
\end{align*}
\]
Varying $\phi$: $R \sin \theta \, d\phi$
A Sphere in 4 Euclidean Dimensions

\[ w \]

\[ R \sin \psi \]

\[ \sqrt{x^2 + y^2 + z^2} \]