

BASICS OF TOPOLOGICAL SPACES

S R DOTY

In these days the angel of topology and the devil of abstract algebra fight for the soul of every individual discipline of mathematics. —Hermann Weyl

1. METRIC SPACES

Topology is the abstract study of continuity. In many situations, one has a way to measure distance between points, and such a metric always leads to a topology. But one can have topology even in situations where a metric is lacking.

1.1. Definition. A metric space is a set X together with a distance function $d : X \times X \rightarrow \mathbb{R}$. The distance function enables us to measure distance between two points of X , and satisfies the properties:

- (1) $d(x, y) \geq 0$
- (2) $d(x, y) = 0$ if and only if $x = y$
- (3) $d(x, y) = d(y, x)$
- (4) $d(x, z) \leq d(x, y) + d(y, z)$

for every $x, y, z \in X$.

The fourth axiom is known as the *triangle inequality*. Of course, Euclidean space $\mathbb{R}^n$ is a metric space with distance function given by the familiar distance formula:

$$d(x, y) = |x - y| = \sqrt{(x - y) \cdot (x - y)} = \sqrt{\sum_i (x_i - y_i)^2}$$

where $x = (x_1, \dots, x_n)$, $y = (y_1, \dots, y_n)$ are any points in $\mathbb{R}^n$. The proof that this particular distance function satisfies the triangle inequality is an amusing exercise based on the Schwarz inequality: $|\langle v, w \rangle| \leq |v| \cdot |w|$ for any $v, w \in \mathbb{R}^n$. Using it, we calculate:

$$\begin{aligned} |v + w|^2 &= \langle v + w, v + w \rangle \\ &= \langle v, v \rangle + 2\langle v, w \rangle + \langle w, w \rangle \\ &\leq |v|^2 + 2|v| \cdot |w| + |w|^2 = (|v| + |w|)^2 \end{aligned}$$

whence $|v + w| \leq |v| + |w|$. Upon setting $v = x - y$, $w = y - z$ this gives the triangle inequality. The Schwarz inequality itself is easy to

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