

Solutions to Topology by Conover

niceguy

July 12, 2022

1 Sets and Functions

1.1 Exercises 1.2

1. State precisely what it means when two sets A and B are not equal.

Solution: $A \neq B \implies$ either

- 1) $A \subset B$ and $B \not\subset A$ or
- 2) $B \subset A$ and $A \not\subset B$

1.2 Exercises 2.2

1. What is $\mathcal{P}(\{1, 2, 3\})$

Solution: $\{\emptyset, \{1\}, \{2\}, \{3\}, \{1, 2\}, \{1, 3\}, \{2, 3\}, \{1, 2, 3\}\}$

2. How many elements does a power set of n elements have?

Solution: Observe that each element in the power set either contains a given element from the original set or it does not, hence there are 2 possibilities for each of the n elements. Therefore, a power set of n elements has 2^n elements.

A formal proof likely using induction is left as an exercise.

3. Are the following statements true?

- (a) $x \in X \iff \{x\} \in \mathcal{P}(X)$

Solution: True.

- (b) $\{x\} \in \mathcal{P}(X) \iff \{x\} \subset X$

Solution: True. Consider $\{x\} \in \mathcal{P}(X)$. By definition $x \in X \implies \{x\} \subset X$.
Also $\{x\} \subset X \implies x \in X \implies \{x\} \in \mathcal{P}(X)$ by definition.

(c) $\{x\} \subset \mathcal{P}(X) \iff x \subset X$

Solution: False. $x \not\subset X$ by definition an element cannot be a subset.

2 Topological Spaces and Concepts in General

2.1 Exercise 2.6

1. Let X be a set. Verify that the indiscrete topology, the discrete topology and the finite-complement topology are in fact topologies on X .

Solution:

Indiscrete Topology:

\emptyset and X are open sets, and any intersection/union of open sets are obviously either empty or X .

Discrete Topology:

\emptyset and X are open sets. Since any subset is open, any intersection/union of open sets must be a subset, and hence is open.

Finite-complement Topology:

\emptyset and X are open sets. Let A_i denote open sets. Then $X - \bigcup_i A_i \subseteq X - A_i$, where $X - A_i$ has a finite cardinality by definition. Therefore, $X - \bigcup_i A_i$ also has a finite cardinality, so $\bigcup_i A_i$ is open. Now let B_i denote finitely many open sets. $X - B_i$ is finite, and so is $\bigcup_i (X - B_i)$ (finite union of finite sets is finite). Since $\bigcup_i (X - B_i) = X - \bigcap_i B_i$ which is finite, $\bigcap_i B_i$ is an open set.

2. (a) Verify that Sierpinski space is a topological space.

Solution: It contains \emptyset and X . Since there are only 3 open sets, brute forcing through all possible unions/intersections show that they are also open sets.

- (b) We said that there are only three different topologies that can be assigned to the 2 point set $\{0, 1\}$. Is the collection of $\{\emptyset, \{1\}, \{0, 1\}\}$ one of those three topologies on $\{0, 1\}$?

Solution: Yes. The same approach for (a) can be used here, since this is essentially the Sierpinski space with 0 and 1 reversed.

- (c) What is $\{0, 1\}$ with the finite-complement topology?

Solution: $\{\emptyset, \{0\}, \{1\}, \{0, 1\}\}$

3. List all topologies that can be assigned to a 3 point set.

Solution:

$\{\emptyset, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0, 1\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{0, 1\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{0, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1\}, \{0, 1\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1\}, \{1, 2\}, \{0, 1, 2\}\}$

$\{\emptyset, \{2\}, \{0, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{2\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{1\}, \{0, 1\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{2\}, \{0, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1\}, \{2\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{0, 1\}, \{0, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1\}, \{0, 1\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{2\}, \{0, 2\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{1\}, \{0, 1\}, \{0, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{2\}, \{0, 1\}, \{0, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{1\}, \{0, 1\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1\}, \{2\}, \{0, 1\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{2\}, \{0, 2\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{1\}, \{2\}, \{0, 2\}, \{1, 2\}, \{0, 1, 2\}\}$
 $\{\emptyset, \{0\}, \{1\}, \{2\}, \{0, 1\}, \{0, 2\}, \{1, 2\}, \{0, 1, 2\}\}$

4. Verify that the Sorgenfrey topology defined on the real line is in fact a topology. Is the interval $(0, 1)$ open in this topology? How about $(0, 1]$? Is $[0, 1]$ closed?

Solution:

The Sorgenfrey topology obviously contains \emptyset and \mathbb{R} . Let A_i denote open sets. Then

$$\forall x \in \bigcup_i A_i, x \in A_i \Rightarrow x \in [a, b) \subseteq A_i \subseteq \bigcup_i A_i$$

so any union of open sets is open. Now let B_i denote finitely many open sets. Now if $x \in B_i$, we let $\{p_i, q_i\} \subset \mathbb{R}$ such that $x \in [p_i, q_i) \subseteq B_i$. Let $P = \{p_i\}$ and $Q = \{q_i\}$. Since both P and Q are finite, P has a maximum p and Q has a minimum q . Now

$$x \in \bigcap_i B_i \Rightarrow x \in [p, q) \subseteq [p_i, q_i) \subseteq B_i \forall i$$

Since $[p, q)$ is a subset of $B_i \forall i$, it is a subset of $\bigcap_i B_i$, hence any finite intersection of open sets is open. This shows that the Sorgenfrey topology is a topology.

$(0, 1)$ is open, because

$$\forall x \in (0, 1), x \in [x, 1) \subset (0, 1)$$

$(0, 1]$ is not open, because $1 \in (0, 1]$, but if $1 \in [a, b)$, then $\frac{1+b}{2}$ is an element of $[a, b)$ but not $(0, 1]$, so $1 \in [a, b) \subseteq (0, 1]$ cannot be true.

Consider $A = \mathbb{R} - [0, 1]$ and let $x \in A$. Either $x < 0$, and $x \in [x, \frac{x}{2}) \subset A$, or $x > 1$, and $x \in [x, x+1) \subset A$. Therefore, A is open, so $[0, 1]$ is closed.

5. Consider the topological spaces $(\mathbb{R}, \mathcal{I})$, $(\mathbb{R}, \mathcal{D})$, $(\mathbb{R}, \mathcal{U})$, $(\mathbb{R}, \mathcal{S})$ and with the finite-complement topology (where \mathcal{U} denotes the usual topology on \mathbb{R} in Chapter 3).

- (a) If $p \in \mathbb{R}$, is $\{p\}$ open in any of these spaces? Which ones?

Solution: $(\mathbb{R}, \mathcal{D})$.

- (b) If $p \in \mathbb{R}$, is $\{p\}$ closed in any of these spaces? Which ones?

Solution: $(\mathbb{R}, \mathcal{D}), (\mathbb{R}, \mathcal{U}), (\mathbb{R}, \mathcal{S})$, and the finite-complement topology.

6. In which of these spaces is (a, b) open? $[a, b)$? $(a, b]$? $[a, b]$?

Solution:

(a, b) :
 $(\mathbb{R}, \mathcal{D}), (\mathbb{R}, \mathcal{U}), (\mathbb{R}, \mathcal{S})$
 $[a, b)$:
 $(\mathbb{R}, \mathcal{D}), (\mathbb{R}, \mathcal{S})$
 $(a, b]$:
 $(\mathbb{R}, \mathcal{D})$
 $[a, b]$:
 $(\mathbb{R}, \mathcal{D})$

- (a) Is the set $\{x \in \mathbb{R} : x \neq \frac{1}{n}\}$ open in any of the spaces? Is it closed in any of them?

Solution:

Open:
 $(\mathbb{R}, \mathcal{D})$
 Closed:
 $(\mathbb{R}, \mathcal{D})$

- (b) Is the set $\{x \in \mathbb{R} : x \neq \frac{1}{n} \text{ and } x \neq 0\}$ open in any of the spaces? Is it closed in any of them?

Solution:

Open:
 $(\mathbb{R}, \mathcal{D})$
 Closed:
 $(\mathbb{R}, \mathcal{D}), (\mathbb{R}, \mathcal{U}), (\mathbb{R}, \mathcal{S})$

7. Consider the spaces of Problem 5 above again, together with the three spaces that can be defined on $\{0, 1\}$.

- (a) In which of these spaces are true: If x and y are two distinct points in the space then either there exists an open set U such that $x \in U$ and $y \notin U$, or there exists an open set V such that $y \in V$ and $x \notin V$. (A space for which this statement holds is called a T_0 -space.)

Solution: $(\mathbb{R}, \mathcal{D}), (\mathbb{R}, \mathcal{U}), (\mathbb{R}, \mathcal{S})$, the finite-complement topology, and the Sierpinski space.

- (b) In which of these spaces is the following statement true: If x and Y are two distinct points in the space, then there exists an open set U such that $x \in U$ and $y \notin U$, and there exists an open set v such that $y \in V$ and $x \notin V$. (A space for which this statement holds is called a T_1 -space.)

Solution: $(\mathbb{R}, \mathcal{D}), (\mathbb{R}, \mathcal{U}), (\mathbb{R}, \mathcal{S})$, and the finite-complement topology.

- (c) In which of these spaces is the following statement true: If x and y are two distinct points in the space, then there exist open sets U and V such that $x \in U$, $y \in V$ and $U \cap V = \emptyset$. (A space for which this statement holds is called a T_2 -space or a Hausdorff space.)

Solution: $(\mathbb{R}, \mathcal{D}), (\mathbb{R}, \mathcal{U}), (\mathbb{R}, \mathcal{S})$

8. Show that every T_2 -space is a T_1 -space, and that every T_1 -space is a T_0 -space, and give an example of a T_0 -space that is not a T_1 -space, and an example of a T_1 -space that is not a T_2 -space.

Solution:

T_2 -space $\Rightarrow T_1$ -space: Since $U \cap V \neq \emptyset$, $x \notin V$ and $y \notin U$, so V and U are open sets that make the space a T_1 -space.

T_1 -space $\Rightarrow T_0$ -space: either one of U and V make the space a T_0 -space.

T_0 -space that is not a T_1 -space: the Sierpinski space

T_1 -space that is not a T_2 -space: the finite-complement topology

9. A topological space X is said to be **metrizable** if a metric can be defined on X so that a set is open in the metric topology induced by this metric if and only if it is open in the topology that is already on the space.

- (a) Let X be a set with more than one point. Prove that (X, \mathcal{I}) is *not* metrizable. Thus the indiscrete topology on a set with more than one point is an example of a topological space that is *not* a metric space.

Solution:

If X has more than one point, it has 2 distinct points x and y , where we let $r = d(x, y) > 0$ by the definition of a metric. $S_{\frac{r}{2}}(x)$ is an open space according to the metric. However, it is neither empty (contains x) nor the universe (does not contain y). This forms a contradiction.

- (b) Let X be a set. Define a function from $X \times X = \{(x, y) : x, y \in X\}$ to \mathbb{R} by

$$d(x, y) = \begin{cases} 1 & \text{if } x \neq y \\ 0 & \text{if } x = y \end{cases}$$

Prove that d is a metric on X . What is the metric topology induced by d ?

Solution:

Obviously, $d(x, y) = 0$ if and only if $x = y$, $d(x, y) \geq 0$, $d(x, y) = d(y, x)$. For the triangle inequality $d(x, y) \leq d(x, z) + d(y, z)$, note that it is trivial if $x = y$. If not, at least one of $d(x, z)$ and $d(y, z)$ must be nonzero, so the inequality holds. Therefore, $d(x, y)$ is a metric.

$\forall x \in X, S_{0.5}(x) = \{x\}$. Since all singleton sets are open, the metric topology induced by d is the discrete topology.