

Munkres - Topology - Chapter 3 Solutions

Section 24

Problem 24.3.

Solution: Define $g : X \rightarrow \mathbb{R}$ where $g(x) = f(x) - i_{\mathbb{R}}(x) = f(x) - x$ where $i_{\mathbb{R}}$ is the identity function. Since f and $i_{\mathbb{R}}$ are continuous, g is continuous by Theorems 18.2(e) and 21.5. Since X is connected for all three possibilities given in this problem and \mathbb{R} is ordered, the intermediate-value theorem applies.

For $X = [0, 1]$, observe that $g(0) \geq 0 - 0 = 0$ and $g(1) \leq 1 - 1 = 0$. Clearly if either $g(0)$ or $g(1)$ equals 0, then there is an $x_0 \in X$ where $f(x_0) - x_0 = 0$, so $f(x_0) = x_0$. Otherwise, $g(0) > 0$ and $g(1) < 0$, so by the intermediate-value theorem there is some $x_1 \in X$ where $g(x_1) = 0$, so $f(x_1) = x_1$.

The proposition is not necessarily true if $X = [0, 1)$ or $X = (0, 1]$. Let $f(x) = (1+x)/2$, which is obviously continuous. It follows that $f(x) = x$ if and only if $x = 1$, which not in X .

Problem 24.4.

Solution: If X has only one element, it is trivially a linear continuum, so we will assume X has at least two elements. Let $x, y \in Y$ where $x < y$. Since X is connected, $(-\infty, y)$ and (x, ∞) cannot be a separation of the space. Since the two open sets are clearly non-empty, it must be that they are not disjoint. Therefore there is some $z \in (-\infty, y) \cap (x, \infty)$, from which it follows that $z < y$ and $x < z$. We infer that $x < z < y$.

Next, let Y be a non-empty subset of X that is bounded above, and suppose Y has no supremum. Define $M = \{m \in X : m \geq y \text{ for all } y \in Y\}$ (in other words, the set of upper bounds of Y). Since Y is bounded above, M is non-empty. Then let $A = \bigcup_{y \in Y} (-\infty, y)$ and $B = \bigcup_{m \in M} (m, \infty)$. It follows that A and B are a separation of X , contradicting that X is connected. Given $x_0 \in X$, if $x_0 < y$ for some $y \in Y$, then $x_0 \in (-\infty, y) \subset A$. On the other hand, if $x_0 \geq y$ for all Y , then there is some $m \in M$ such that $m < x_0$, so $x_0 \in (m, \infty) \subset B$. Hence A and B partition X . Further, if $x_1 \in A \cap B$, then $x_1 < y$ for some $y \in Y$ and $x_1 > y'$ for all $y' \in Y$, which is impossible. Therefore A and B are disjoint. Since A and B form an impossible separation of X , we conclude that Y must have a supremum. Accordingly, X is a linear continuum.

Problem 24.4.

Solution: Given $x, y \in X \times [0, 1]$ where $x < y$, we have $x = x_0 \times x_1$ and $y = y_0 \times y_1$. Since $[0, 1]$ is a linear continuum, if $x_0 < y_0$, let $z_1 \in (x_1, 1)$; if $x_0 = y_0$, let $z_1 \in (x_1, y_1)$. Hence if $z = x_0 \times z_1$, then $x < z < y$.

Now let U be a non-empty subset of $X \times [0, 1]$ that is bounded above. Define $M = \{m \in X \times [0, 1] : m \geq a \text{ for all } a \in U\}$, which is the set of all upper bounds of U . Since U is bounded above, we're assured that M is non-empty. Designate $V = \{\pi_1(m) : m \in M\}$, which must be a non-empty subset of X . Since X is well-ordered, there is a least element x' of V . If $x' \notin \pi_1(U)$, then $x' \times 0 > a$ for all $a \in U$. Further, if $x'' < x'$, then any element of $x'' \times [0, 1]$ must be less than some element of U because no upper bound of U has a first coordinate less than x' . Hence $x' \times 0$ is the supremum of U . On the other hand, if $x' \in \pi_1(U)$, the set $V' = \{\pi_2(a) : a \in U\}$ is a non-empty subset of $[0, 1]$ that is bounded above by 1, so it has a supremum y' . Accordingly, if $c \in [0, y')$, there is some $d > c$ such that $x' \times d \in U$, which is greater than $x' \times c$. Therefore $x' \times y'$ is the supremum of U , and $X \times [0, 1]$ has the supremum property. We conclude that $X \times [0, 1]$ is a linear continuum.

Problem 24.9.

Solution: Designate $X = \mathbb{R}^2 \setminus A$, and let $x, y \in X$ be given. If there is no element of A on the straight-line path in \mathbb{R}^2 from x to y , then there is obviously a path between the two points by exercise 24.8(a). In the non-trivial case where there is an element of A on the straight-line path between x and y , designate $D_0 = \{\theta \in [0, 2\pi) : \tan^{-1}[(\pi_2(a) - \pi_2(x))/(\pi_1(a) - \pi_1(x))] \neq \theta \text{ for all } a \in A\}$, which are all the angles around x for which there is no element of A on the straight line passing through x at that angle. We will show that D_0 is not empty. Assume the contrary is true and D_0 is empty. It would follow that for every element of the interval $[0, 2\pi)$, there is some element of A on the line at that angle. Consequently, there is an injection from $[0, 2\pi) \rightarrow A$. Because A is countable, there would be an injection from $[0, 2\pi) \rightarrow \mathbb{N}$, establishing that $[0, 2\pi)$ is countable, a contradiction. Therefore D_0 is not empty. Choose an arbitrary θ_0 from D_0 .

Topology Munkres Solutions Chapter 9

A Gutmann



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