James Munkres - Topology

Carter Hinsley's notes

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29 Local Compactness

Definition. A space X is *locally compact at x* if there is some compact subspace C of X that contains a nbhd of x. If X is locally compact at each of its points, X is said to be *locally compact.*

We ask: "Under what conditions is a space homeomorphic with a subspace of a compact Hausdorff space?"

Theorem 29.1. Let X be a space. X is locally compact Hausdorff iff there exists a space Y satisfying the following conditions:

- X is a subspace of Y.
- $Y - X$ comprises a single point.
- Y is a compact Hausdorff space.

Definition. If Y is a compact Hausdorff space and X is a proper subspace of Y dense in Y, then Y is said to be a *compactification* of X. If $Y - X$ equals a single point, then Y is called the *one-point compactification* of X.

Theorem 29.2. Let X be a Hausdorff space. Then X is locally compact iff given $x \in X$ and a nbhd U of x, there is a nbhd V of x such that $\overline{V}$ is compact and $\overline{V} \subset U$.

Corollary 29.3. Any open or closed subspace of a locally compact Hausdorff space is itself locally compact.

Corollary 29.4. A space X is homeomorphic to an open subspace of a compact Hausdorff space iff X is locally compact Hausdorff.

Exercises

(1) Show that the rationals $\mathbb{Q}$ are not locally compact.

Proof. It will be sufficient to show that $\mathbb{Q}$ is not locally compact at 0; i.e., that there is no compact subspace of $\mathbb{Q}$ containing a neighborhood of 0.

Suppose for the sake of contradiction that there existed a compact subspace C of $\mathbb{Q}$ and an open nbhd U of 0 in C. Then there would be some open nbhd $(-\varepsilon, \varepsilon) \cap \mathbb{Q} \subseteq U$ of 0. Note that the inclusion $\mathbb{Q} \overset{\iota}{\hookrightarrow} \mathbb{R}$ is continuous; this map preserves compactness. Hence $\iota(C)$ is compact in $\mathbb{R}$. As $\mathbb{R}$ is Hausdorff, $\iota(C)$ is closed in $\mathbb{R}$. Thus $[-\varepsilon, \varepsilon] = \overline{(-\varepsilon, \varepsilon) \cap \mathbb{Q}} \subseteq \iota(C)$. Since $[-\varepsilon, \varepsilon]$ is uncountable while $\iota(C)$ is countable, we obtain a contradiction. Hence $\mathbb{Q}$ is not locally compact. $\square$

Supplementary Exercises: Nets

Nets are generalizations of sequences that characterize limit points, continuous functions, and compact sets not only in metric topologies, but in *all* topologies.

Definition. A *directed set* J is a poset wherein for each pair $\alpha, \beta \in J$, there exists an element $\gamma \in J$ such that $\alpha \preceq \gamma$ and $\beta \preceq \gamma$.

(1) Show that the following are directed sets:

- Any simply ordered set, under the relation $\leq$.
- The collection of all subsets of a set S, partially ordered by inclusion.
- A collection $\mathscr{A}$ of subsets of S that is closed under finite intersections, partially ordered by reverse inclusion.
- The collection of all closed subsets of a space X, partially ordered by inclusion.

(2) A subset K of J is said to be *cofinal* in J if for each $\alpha \in J$, there exists $\beta \in K$ such that $\alpha \preceq \beta$. Show that if J is a directed set and K is cofinal in J, then K is a directed set.

(3) Let X be a topological space. A *net* in X is a function f from a directed set J into X. If $\alpha \in J$, we usually denote $f(\alpha)$ by x_α. We denote the net f itself by the symbol $(x_\alpha)_{\alpha \in J}$, or merely by (x_α) if the index set is understood.

The net (x_α) is said to *converge* to the point $x \in X$ (written $x_\alpha \to x$) if for each nbhd U of x, there exists $\alpha \in J$ such that $\alpha \preceq \beta \implies x_\beta \in U$ Show that these definitions reduce to familiar ones when $J = Z_+$.

(4) Suppose that $(x_\alpha)_{\alpha \in J} \to x \in X$ and $(y_\alpha)_{\alpha \in J} \to y \in Y$. Show that $(x_\alpha \times y_\alpha) \to x \times y \in X \times Y$.

(5) Show that if X is Hausdorff, a net in X converges to at most one point.

(6) **Theorem.** Let $A \in X$. Then $x \in \overline{A}$ iff there is a net of points of A converging to x.

(7) **Theorem.** Let $f : X \to Y$. Then f is continuous iff for every convergent net $(x_\alpha) \to x$ in X, the net $(f(x_\alpha))$ converges to $f(x)$.