

MA571: Qual Preparation

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1 Gepner's homework

1.1 Homework 1

Exercise 1.1. Let $\{X_i : i \in I\}$ be an I -indexed family of topological spaces. Show that the Cartesian product

$$X = \prod_{i \in I} X_i,$$

equipped with the product topology, has the property that for each $i \in I$ the projection $p_i : X \rightarrow X_i$ is continuous, and moreover, that X has the following universal property: for any other topological space Y , the function

$$\mathrm{Hom}_{\mathbf{Top}}(Y, X) \longrightarrow \prod_{i \in I} \mathrm{Hom}_{\mathbf{Top}}(Y, X_i),$$

induced by the projections $p_i : X \rightarrow X_i$, is a bijection.

Solution. ■

Exercise 1.2. Let X be the set equipped with a topology and let $\{\mathcal{U}_i : i \in I\}$ a family of topologies on X . Show that

$$\mathcal{U} = \bigcap_{i \in I} \mathcal{U}_i$$

is a topology on X . Show that if \mathcal{B} is a basis for a topology on X , then the topology \mathcal{U} on X generated by \mathcal{B} is the intersection of all topologies on X which contain \mathcal{B} , and that this holds even if we only require that \mathcal{B} be a subbasis.

Solution. ■

Exercise 1.3. A topological space X is said to be *Hausdorff* if, for every pair of points $x_0, x_1 \in X$ with $x_0 \neq x_1$, there exists open subsets U_0, U_1 of X such that $x_0 \in U_0$, $x_1 \in U_1$, and $U_0 \cap U_1 = \emptyset$. Show that a topological space X is Hausdorff if and only if the diagonal inclusion $X \rightarrow X \times X$ is closed.

Solution. ■

Exercise 1.4. Let X be a topological space and let $Y \subseteq X$ be a subset of X . Show that if Y is equipped with the subspace topology then the inclusion function $i : Y \rightarrow X$ is continuous. Show that if there exists a continuous function $q : X \rightarrow Y$ such that $q \circ i = \mathrm{id}_Y$ then q is a quotient map (that is, Y is also a quotient topology). Give an example of such a situation.

Solution. ■

Exercise 1.5. A *topological group* is a group G with a topology \mathcal{U} such that the multiplication $\mu: G \times G \rightarrow G$ and inversion $i: G \rightarrow G$ are continuous (it is standard to also assume that the topology \mathcal{U} on G is Hausdorff, which we shall do). Let H be a subgroup of G , and let G/H denote the quotient of G by the action of H , equipped with the quotient topology. Show that G/H is a homogeneous space and that the quotient map $q: G \rightarrow G/H$ is open. If, moreover, H is a closed subset of G , show that G/H has the property that points are closed. Finally, show that if H is a normal subgroup of G , then G/H is a topological group. (Optional: is it Hausdorff?)

Solution. ■

2 Homework 2

Exercise 2.1. A topological space X is said to be totally disconnected if a subspace $Y \subseteq X$ is connected if and only if $Y = \{x\}$ consists of only a single point $x \in X$. Show that if X is discrete (that is, all subsets of X are open) then X is totally disconnected. Find an example of a totally disconnected space which is not discrete.

Solution. ■

Exercise 2.2. Let X be a simply ordered set equipped with the order topology. Show that if X is connected then X is a continuum.

Solution. ■

Exercise 2.3. Show that a metric $d: X \times X \rightarrow \mathbf{R}$ on a set X determines a coarsest topology \mathcal{U} on X for which the distance function $d: X \times X \rightarrow \mathbf{R}$ is continuous, and give an explicit basis for this topology. Recall that a function $f: X \rightarrow Y$ between metric spaces is said to be continuous at x if, for all $\varepsilon > 0$ there exists a $\delta > 0$ such that if $d(x, x_0) < \delta$ then $d(f(x), f(x_0)) < \varepsilon$; show that f is continuous (in the sense of topology) if and only if it is continuous at x for all $x \in X$. Finally, show that every compact subspace of a metric space is closed and bounded, and find an example of a metric space for which there exists a closed and bounded subspace which is not compact.

Solution. ■

Exercise 2.4. Let X be a compact space, Y a Hausdorff space, and $f: X \rightarrow Y$ a continuous function. Show that f is a closed map (that is, f sends closed sets to closed sets), and also that the projection $p: X \times Y \rightarrow Y$ is a closed map.

Solution. ■

Exercise 2.5. Let $f: W \rightarrow X$ and $g: W \rightarrow Y$ be continuous functions. The pushout $X \amalg_W Y$ of f and g is the quotient of the disjoint union $X \amalg Y$ by the equivalence relation generated by the relation $x \sim y$ if there exists a $w \in W$ such that $x = f(w)$ and $y = g(w)$. Show that $X \amalg_W Y$ comes equipped with continuous functions $i: X \rightarrow X \amalg_W Y$ and $j: Y \rightarrow X \amalg_W Y$ such that $i \circ f = j \circ g$, and is universal among topological spaces Z equipped with continuous functions $i': X \rightarrow Z$ and $j': Y \rightarrow Z$ such that $i' \circ f = j' \circ g$ in the following sense: given any such space Z , there exists a unique continuous function $k: X \amalg_W Y \rightarrow Z$ such that $i' = k \circ i$ and $j' = k \circ j$.

Solution. ■