TOPOLOGICAL SPACES

ARTHUR RYMAN

ABSTRACT. This article contains Z Notation definitions for topological spaces and related concepts. It has been type checked by *f*UZZ.

CONTENTS

1. Topological Spaces 1
2. Continuous Mappings 3
3. Induced Topology 4
4. Product Topology 4

1. TOPOLOGICAL SPACES

1.1. *Topology*. A *topology* τ on X is a family of subsets of X, referred to as the *open* subsets of X, that satisfy the following axioms.

Topology[X]

$\tau : \mathcal{F}\, X$

$\varnothing \in \tau$

$X \in \tau$

$\forall F : \mathbb{F}\, \tau \bullet \bigcap F \in \tau$

$\forall F : \mathbb{P}\, \tau \bullet \bigcup F \in \tau$

- The empty set is open.
- The whole set is open.
- The intersection of a finite family of open sets is open.
- The union of any family of open sets is open.

Date: October 29, 2023.

1.2. *top* and *tops*.

Let $top[X]$ denote the set of all topologies on X.

$$
\begin{array}{|l}
[X] \\
\hline
top : \mathbb{P}(\mathcal{F}\, X) \\
\hline
top = \{\, Topology[X] \bullet \tau \,\}
\end{array}
$$

Let $tops[X]$ denote the set of all topologies on subsets $U \subseteq X$.

$$
\begin{array}{|l}
[X] \\
\hline
tops : \mathbb{P}(\mathcal{F}\, X) \\
\hline
tops = \bigcup\{\, U : \mathbb{P}\, X \bullet top[U] \,\}
\end{array}
$$

1.3. *discrete* and *indiscrete*.

The *discrete* topology on X consists of all subsets of X. The *indiscrete* topology on X consists of just X and $\varnothing$. Let $discrete[X]$ and $indiscrete[X]$ denote the discrete and indiscrete topologies on X.

$$
\begin{array}{|l}
[X] \\
\hline
discrete, indiscrete : \mathcal{F}\, X \\
\hline
discrete = \mathbb{P}\, X \\
indiscrete = \{\varnothing, X\}
\end{array}
$$

Example. *Let* X *be an arbitrary set. Then* $discrete[\mathsf{X}]$ *and* $indiscrete[\mathsf{X}]$ *are topologies on* X.

$discrete[\mathsf{X}] \in top[\mathsf{X}]$

$indiscrete[\mathsf{X}] \in top[\mathsf{X}]$

1.4. *topGen*.

Remark. *The intersection of a set of topologies on* X *is also a topology on* X.

Given a family B of subsets of X, the topology *generated by* B is the intersection of all topologies that contain B. The set B is referred to as a *basis* for the topology it generates. Let $topGen[X]\, B$ denote the topology on X generated by the basis B.

$$
\begin{array}{|l}
[X] \\
\hline
topGen : \mathcal{F}\, X \longrightarrow top[X] \\
\hline
\forall\, B : \mathcal{F}\, X \bullet \\
\qquad topGen\, B = \bigcap\{\, \tau : top[X] \mid B \subseteq \tau \,\}
\end{array}
$$

Example. *Let* X *be an arbitrary set.*

$topGen[\mathsf{X}]\varnothing = indiscrete[\mathsf{X}]$

$topGen[\mathsf{X}]\{\varnothing\} = indiscrete[\mathsf{X}]$

$topGen[\mathsf{X}]\{\mathsf{X}\} = indiscrete[\mathsf{X}]$

1.5. *topSpace*. Let X be a set. A *topological space* is a pair (X, τ) where τ is a topology on X. Let $topSpace[X]$ denote the set of all topological spaces (X, τ).

$$topSpace[X] == \{ \tau : top[X] \bullet (X, \tau) \}$$

Example. *Let* X *be an arbitrary set.*

$$(\mathsf{X}, indiscrete[\mathsf{X}]) \in topSpace[\mathsf{X}]$$

$$(\mathsf{X}, discrete[\mathsf{X}]) \in topSpace[\mathsf{X}]$$

1.6. *topSpaces*. Let $topSpaces[t]$ dentote the set of all topological spaces (X, τ) where X is a subset of t.

$$
\begin{array}{|l}
[t] \\
\hline
topSpaces : \mathbb{P}\, t \leftrightarrow \mathcal{F}\, t \\
\hline
topSpaces = \{ X : \mathbb{P}\, t; \tau : \mathcal{F}\, t \mid \tau \in top[X] \} \\
\hline
\end{array}
$$

Remark.

$$topSpace[\mathsf{X}] \subseteq topSpaces[\mathsf{X}]$$

2. Continuous Mappings

Let (X, τ) and (Y, σ) be topological spaces.

2.1. *Continuous*. A mapping $f \in X \longrightarrow Y$ is said to be *continuous* if the inverse image of every open set is open.

$$
\begin{array}{|l}
Continuous[X, Y] \\
\hline
f : X \longrightarrow Y \\
\tau : top[X] \\
\sigma : top[Y] \\
\hline
\forall\, U : \sigma \bullet \\
\qquad f^{\sim}(\!| U |\!) \in \tau \\
\hline
\end{array}
$$

2.2. C^0 `\CzeroTT`. Let A and B be topological spaces, and let $\mathrm{C}^0(A, B)$ denote the set of continuous mappings from A to B.

$$
\begin{array}{|l}
[X, Y] \\
\hline
\mathrm{C}^0 : topSpace[X] \times topSpace[Y] \longrightarrow \mathbb{P}(X \longrightarrow Y) \\
\hline
\forall\, \tau : top[X]; \sigma : top[Y] \bullet \\
\qquad \mathbf{let}\ A == (X, \tau); B == (Y, \sigma) \bullet \\
\qquad\qquad \mathrm{C}^0(A, B) = \{ f : X \longrightarrow Y \mid Continuous[X, Y] \} \\
\hline
\end{array}
$$

2.3. **The Identity Mapping.**

Remark. *The identity mapping is continuous.*

$$
\begin{array}{l}
\forall\, \tau : top[\mathsf{X}] \bullet \\
\qquad \mathbf{let}\ A == (\mathsf{X}, \tau) \bullet \\
\qquad\qquad \mathrm{id}\,\mathsf{X} \in \mathrm{C}^0(A, A)
\end{array}
$$

Remark. *The constant mapping is continuous.*

$$
\begin{array}{l}
\forall\, \tau : \mathit{top}[\mathsf{X}];\ \sigma : \mathit{top}[\mathsf{Y}];\ c : \mathsf{Y} \bullet \\
\quad \mathbf{let}\ A == (\mathsf{X}, \tau);\ B == (\mathsf{Y}, \sigma) \bullet \\
\qquad \mathrm{const}[\mathsf{X}, \mathsf{Y}]\, c \in \mathrm{C}^0(A, B)
\end{array}
$$

2.4. Composition of Continuous Mapping.

Remark. *Let* X*,* Y*, and* Z *be arbitrary sets. The composition of continuous mappings is a continuous mapping.*

$$
\begin{array}{l}
\forall\, A : \mathit{topSpace}[\mathsf{X}];\ B : \mathit{topSpace}[\mathsf{Y}];\ C : \mathit{topSpace}[\mathsf{Z}] \bullet \\
\quad \forall\, f : \mathrm{C}^0(A, B);\ g : \mathrm{C}^0(B, C) \bullet \\
\qquad g \circ f \in \mathrm{C}^0(A, C)
\end{array}
$$

3. Induced Topology

Let $A = (X, \tau)$ be a topological space and let $U \subseteq X$ be a subset. The topology on X *induces* a topology on U. This topology is variously referred to as the *induced*, *relative*, or *subspace* topology on U.

3.1. $|_{\mathcal{F}}$ `\inducedFam`**.** Let ϕ be a family of subsets of X and let U be a subset of X. The family of subsets of U *induced* by ϕ is the set of intersections of the members of ϕ with U. Let $\phi \,|_{\mathcal{F}}\, U$ denote the family on U induced by ϕ.

$$
\begin{array}{|l}
[X] \\
\hline
\_ \,|_{\mathcal{F}}\, \_ : \mathcal{F}\, X \times \mathbb{P}\, X \longrightarrow \mathcal{F}\, X \\
\hline
\forall\, \phi : \mathcal{F}\, X;\ U : \mathbb{P}\, X \bullet \\
\qquad \phi \,|_{\mathcal{F}}\, U = \{\, Y : \phi \bullet Y \cap U \,\} \\
\hline
\end{array}
$$

Remark. *If* τ *is a topology on* X *then* $\tau \,|_{\mathcal{F}}\, U$ *is a topology on* U*.*

$$
\begin{array}{l}
\forall\, \tau : \mathit{top}[\mathsf{X}];\ U : \mathbb{P}\, \mathsf{X} \bullet \\
\quad \tau \,|_{\mathcal{F}}\, U \in \mathit{top}[U]
\end{array}
$$

3.2. $|_{\mathsf{top}}$ `\inducedTopSp`**.** Let $(X, \tau) \,|_{\mathsf{top}}\, U$ denote the corresponding induced topological space.

$$
\begin{array}{|l}
[X] \\
\hline
\_ \,|_{\mathsf{top}}\, \_ : \mathit{topSpace}[X] \times \mathbb{P}\, X \longrightarrow \mathit{topSpaces}[X] \\
\hline
\forall\, \tau : \mathit{top}[X];\ U : \mathbb{P}\, X \bullet \\
\qquad (X, \tau) \,|_{\mathsf{top}}\, U = (U, \tau \,|_{\mathcal{F}}\, U) \\
\hline
\end{array}
$$

4. Product Topology

Let (X, τ) and (Y, σ) be topological spaces. There is a natural topology on $X \times Y$ generated by the products of the sets in τ and σ.

4.1. $\times_{\mathcal{F}}$ `\prodFam`. Let X and Y be sets and let ϕ and ψ be families on them. The product of these families is the family that consists of the products of the sets in them and is a family on $X \times Y$. Let $\phi \times_{\mathcal{F}} \psi$ denote the product of the families.

$$
\begin{array}{l}
[X, Y] \\
\hline
\_ \times_{\mathcal{F}} \_ : \mathcal{F}\, X \times \mathcal{F}\, Y \longrightarrow \mathcal{F}(X \times Y) \\
\hline
\forall\, \phi : \mathcal{F}\, X;\ \psi : \mathcal{F}\, Y \bullet \\
\qquad \phi \times_{\mathcal{F}} \psi = \{\, U : \phi;\ V : \psi \bullet U \times V \,\}
\end{array}
$$

Remark. *If τ and sigma are topologies then $\tau \times_{\mathcal{F}} \sigma$ is not, in general, a topology. However, we can use it to generate a topology.*

4.2. $\times_{\mathsf{top}}$ `\prodTop`. Let $\tau \times_{\mathsf{top}} \sigma$ denote the topology generated by $\tau \times_{\mathcal{F}} \sigma$.

$$
\begin{array}{l}
[X, Y] \\
\hline
\_ \times_{\mathsf{top}} \_ : \mathit{top}[X] \times \mathit{top}[Y] \longrightarrow \mathit{top}[X \times Y] \\
\hline
\forall\, \tau : \mathit{top}[X];\ \sigma : \mathit{top}[Y] \bullet \\
\qquad \tau \times_{\mathsf{top}} \sigma = \mathit{topGen}(\tau \times_{\mathcal{F}} \sigma)
\end{array}
$$

4.3. $\times_{\mathsf{top}}$ `\prodTopSp`. Let $(X, \tau) \times_{\mathsf{top}} (Y, \sigma)$ denote the product topological space.

$$
\begin{array}{l}
[X, Y] \\
\hline
\_ \times_{\mathsf{top}} \_ : \mathit{topSpace}[X] \times \mathit{topSpace}[Y] \longrightarrow \mathit{topSpace}[X \times Y] \\
\hline
\forall\, \tau : \mathit{top}[X];\ \sigma : \mathit{top}[Y] \bullet \\
\qquad (X, \tau) \times_{\mathsf{top}} (Y, \sigma) = (X \times Y, \tau \times_{\mathsf{top}} \sigma)
\end{array}
$$

Email address, Arthur Ryman: `arthur.ryman@gmail.com`