Part I
Manifolds

1 Elementary Topology

1.1 Topological Spaces

Topology

For a collection of points X, $\mathcal{T} \subseteq \mathcal{P}(X)$ satisfies

1. $\emptyset$, $X \in \mathcal{T}$
2. $\bigcup_{i \in I} \mathcal{O}_i \in \mathcal{T}$ where $\mathcal{O}_i \in \mathcal{T}$
3. $\bigcap_{i \in I} \mathcal{O}_i \in \mathcal{T}$ where $\mathcal{O}_i \in \mathcal{T}$ and I is finite

called a **topology** on X. A set X endowed with a topology $\mathcal{T}$ is called **topological space**.

Open Sets

Elements of $\mathcal{T}$ are called **open sets**.

1.2 Neighbourhoods and Hausdorff Spaces

Neighbourhood

For a point $P \in X$, a subset $\mathcal{N} \subseteq \mathcal{T}$ is called **neighbourhood** of P, if there exists an open set $\mathcal{O}$ such that $P \in \mathcal{O} \subseteq \mathcal{N}$.

Hausdorff Space

For arbitrary points p_1, p_2 in topological space $(X, \mathcal{T}$, if there exist neighbourhoods $\mathcal{N}_1 \ni p_1$ and $\mathcal{N}_2 \ni p_2$ such that $\mathcal{N}_1 \cap \mathcal{N}_2 = \emptyset$, the space is called **Hausdorff space**.

1.3 Homeomorphism

Continuity of Maps

Suppose a map $f : X_1 \to X_2$ between topological spaces $(X_1, \mathcal{T}_1)$ and $(X_2, \mathcal{T}_2)$. For an arbitrary open set $\mathcal{O} \in X_2$, if $f^{-1}(\mathcal{O}) \in \mathcal{T}_1$, f is said to be **continuous**.

Homeomorphism

A map $f : X_1 \to X_2$ between topological spaces X_1 and X_2 is called **homeomorphism** if it satisfies

1. f is bijective
2. f is continuous
3. Inverse of f is continuous

Topological spaces X_1 and X_2 are said to be **homeomorphic** if there exists homeomorphism between the spaces.

2 Manifolds

2.1 Definition

Manifold is a *locally euclidean*(i.e., locally homeomorphic to euclidean space) topological space.

Charts

Let $(M, \mathcal{T})$ be a topological space. For an open set $\mathcal{O} \in M$ and a homeomorphism $\phi : \mathcal{O} \to \mathbb{R}^n$, a pair $(\mathcal{O}, \phi)$ is called a **chart** on a topological space M.

Topological Manifold

For every open set $\mathcal{O}_i \in \mathcal{T}$, if M covered with charts $\phi_i : \mathcal{O}_i \to \mathbb{R}^n$, M is said to be an n-dimensional **topological manifold**.

Coordinates

For every point $p \in M$, a tuple $\phi(p) = (x^1(p), x^2(p), \cdots, x^n(p))$ is called a **coordinate** of p.

Atlas

For a manifold M, an atlas $\{(\mathcal{O}_i, \phi_i)\}$ is a collection of whole charts consisting M.

2.2 Differentiability

Transition Map

Let M be a manifold whose atlas is $\{(\mathcal{O}_i, \phi_i)\}$. For open sets $\mathcal{O}_i.\mathcal{O}_j \in M$ such that $\mathcal{O}_1 \cap \mathcal{O}_2 \neq \emptyset$, a map $\phi_{ij} : \phi_i(\mathcal{O}_1 \cap \mathcal{O}_2) \to \phi_j(\mathcal{O}_1 \cap \mathcal{O}_2)$ is called **transition map**.

Differentiability of Manifolds

If transition maps of M are differentiable up to kth order(i.e., is C^k map), the manifold is said to be C^k manifold. C^0, C^∞, C^ω manifolds are also defined in a natural way.