

An Introduction to Hilbert Spaces

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2008

1 Inner-Product Spaces

Hilbert spaces provide a user-friendly framework for the study of a wide range of subjects, from Fourier Analysis to Quantum Mechanics. Ideas from linear algebra underlie much of what follows, so we begin with a brief review of linear (or vector) spaces.

Definition: A linear space is a set X with an associated scalar field \mathbb{F} (in this course either \mathbb{R} or \mathbb{C}) on which the following linear operations are defined:

1. Vector addition, which takes each pair of elements x and y in X to another element $x + y$ of X :

$$X \times X \rightarrow X, \quad (x, y) \mapsto x + y$$

2. Scalar multiplication, which takes each pairing of scalars λ from \mathbb{F} and elements x of X to another element λx of X :

$$X \times \mathbb{F} \rightarrow X, \quad (x, \lambda) \mapsto \lambda x$$

and for which the following conditions are satisfied:

- i) Vector addition is commutative: $x + y = y + x \quad \forall x, y \in X$
- ii) Vector addition is associative: $(x + y) + z = x + (y + z) \quad \forall x, y, z \in X$
- iii) Existence of an additive identity for all elements: \exists an element $0 \in X$ such that $0 + x = x \quad \forall x \in X$
- iv) Existence of additive inverses for each element: $\forall x \in X \exists$ a corresponding element $-x \in X$ such that $-x + x = 0$
- v) Scalar multiplication is associative: $(\lambda\mu)x = \lambda(\mu x) \quad \forall x \in X, \forall \lambda, \mu \in \mathbb{F}$
- vi) Scalar multiplication distributes over scalar addition: $(\lambda + \mu)x = \lambda x + \mu x \quad \forall x \in X, \forall \lambda, \mu \in \mathbb{F}$
- vii) Scalar multiplicative identity applies to vectors: $1x = x$ for every element $x \in X$
- viii) Scalar multiplication distributes over vector addition: $\lambda(x + y) = \lambda x + \lambda y \quad \forall x, y \in X, \forall \lambda \in \mathbb{F}$

We will refer to this structure as the linear space X over \mathbb{F} .

As illustrated above, in this course we will adopt the convention of denoting the elements (points or vectors) of the space X by Roman letters x, y, z, \dots and elements of the associated scalar field (either \mathbb{R} or \mathbb{C}) by the Greek letters $\alpha, \beta, \gamma, \dots, \lambda, \dots$. Other notations that are commonly used include the use of bold type (\mathbf{x}), underlining (\underline{x}), arrows (\vec{x}) or 'twiddles' (\tilde{x}) when writing vectors to distinguish them from scalar quantities.

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