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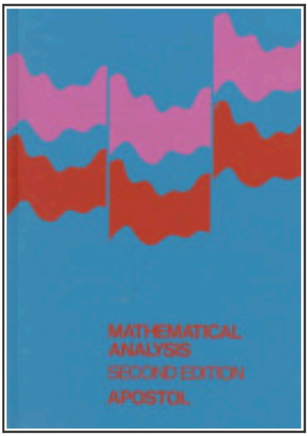

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University of Wisconsin—Madison

Principles of Mathematical Analysis

THIRD EDITION

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First published in 1953 (revised 1964, 1976), "Principles of Mathematical Analysis" has become a classic introduction to the field. Generations of students have become acquainted with this slim, blue-covered volume (fondly referred to as "Baby Rudin"), which continues to be used for honours courses at the top mathematics departments in the US. "Principles of Mathematical Analysis" has also been influential internationally through translated editions in Russian, German, French, and Chinese, among others.

Walter B. Rudin (1921-2010) was an Austrian-American mathematician and Professor of Mathematics at the University of Wisconsin, Madison (1959-1991). He was known for his contributions to complex and harmonic analysis and authorship of several widely adopted textbooks, including "Principles of Mathematical Analysis", "Real and Complex Analysis", and "Functional Analysis".

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Mathematical Background (Appendix A)

1. Norm

Definition: A function $f: \mathbb{R}^n \to \mathbb{R}$ with $\underline{\operatorname{dom} f} = \mathbb{R}^n$ is called a norm if

domain

① $f(x) \geq 0 \quad \forall x \in \mathbb{R}^n$ (nonnegativity)

② $f(x) = 0$ only if $x = 0$.

(f is definite)

③ $f(tx) = |t| f(x) \quad \forall x \in \mathbb{R}^n, t \in \mathbb{R}$

(homogenity)

④ $f(x+y) \leq f(x) + f(y)$

(triangle inequality)

- Denote $f(x) = \| x \|$

which can be considered as a generalization of the absolute value on $\mathbb{R}$.

Example: ℓ_p-norm $p \geq 1$ for $x \in \mathbb{R}^n$ $x = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix}$

$$\| x \|_p \triangleq \left(|x_1|^p + |x_2|^p + \cdots + |x_n|^p \right)^{1/p}.$$

$p=1$: $\| x \|_1 = |x_1| + |x_2| + \cdots + |x_n|$

$p=2$: $\| x \|_2 = \left(|x_1|^2 + |x_2|^2 + \cdots + |x_n|^2 \right)^{1/2}$

$= \left(x_1^2 + x_2^2 + \cdots + x_n^2 \right)^{1/2}.$

(Euclidean norm).

$p = \infty$: (maximum norm / infinity norm)

$$\| x \|_\infty = \lim_{p \to \infty} \| x \|_p = \max \{ |x_1|, |x_2|, \ldots, |x_n| \}$$

Remark: every norm is a convex function.

Quadratic norms

For $P \in S^n_{++}$, $x \in \mathbb{R}^n$

$$\| x \|_P = \left(x^T P x \right)^{1/2}$$
$$= \| P^{1/2} x \|_2$$

$\mathbb{R}^{m \times n}$: matrices

S^n : $n \times n$ symmetric matrices over $\mathbb{R}$.

S^n_+ : $n \times n$ positive semidefinite matrices

$\boxed{S^n_{++} : n \times n \text{ positive definite matrices.}}$

If $P \in S_+^n$,

P has a spectral decomposition $x_i^T x_j = \delta_{ji}$

$$P = \sum_i \lambda_i x_i x_i^T \quad \text{with } \lambda_i \geq 0.$$

$$P^{1/2} \triangleq \sum_i \sqrt{\lambda_i}\, x_i x_i^T.$$

$$P^{1/2} \cdot P^{1/2} = \left(\sum_i \sqrt{\lambda_i}\, x_i x_i^T\right)\left(\sum_j \sqrt{\lambda_j}\, x_j x_j^T\right)$$

$$= \sum_i \sum_j \sqrt{\lambda_i}\sqrt{\lambda_j}\, x_i \underbrace{x_i^T x_j}_{\delta_{ij}} x_j^T$$

$$= P$$

A matrix M is <u>normal</u> if $M^TM = MM^T$.

For a normal matrix $M \in \mathbb{R}^{n\times n}$. $x \in \mathbb{R}^n$

if $Mx = \lambda x$ for some $\lambda \in \mathbb{R}$.

we say that x is an eigenvector of M.

λ eigenvalue.

If M is normal. there exist λ_i, x_i such that

$$M = \sum_i \lambda_i x_i x_i^T.$$

unit vectors

spectral decomposition

$$x_i^T x_j = \delta_{ji}$$

Ex. $M = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$, $MM^T = M^TM$

$$M \frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix} = \sqrt{2}\begin{pmatrix}1\\1\end{pmatrix} = 2\left(\frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix}\right)$$

$$M = 2\left(\frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix}\right)\left(\frac{1}{\sqrt{2}}(1 \quad 1)\right)$$

For a symmetric & normal matrix M,

if all the eigenvalues of M are ≥ 0, (>0)

M is called positive semidefinite.

(positive definite)