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To Volume 1 This work represents our effort to present the basic concepts of vector and tensor analysis. Volume I begins with a brief discussion of algebraic structures followed by a rather detailed discussion of the algebra of vectors and tensors.

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Calculus and Linear Algebra. Vol. 2: Vector Spaces, Many-Variable Calculus, and Differential Equations

This classic volume covers the fundamentals of two closely related topics: linear systems (linear equations and least-squares) and linear programming (optimizing a linear function subject to linear constraints). For each problem class, stable and efficient numerical algorithms intended for a finite-precision environment are derived and analyzed. While linear algebra and optimization have made huge advances since this book first appeared in 1991, the fundamental principles have not changed. These topics were rarely taught with a unified perspective, and, somewhat surprisingly, this remains true 30 years later. As a result, some of the material in this book can be difficult to find elsewhere—in particular, techniques for updating

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the LU factorization, descriptions of the simplex method applied to all-inequality form, and the analysis of what happens when using an approximate inverse to solve  $Ax=b$ . Numerical Linear Algebra and Optimization is primarily a reference for students who want to learn about numerical techniques for solving linear systems and/or linear programming using the simplex method; however, Chapters 6, 7, and 8 can be used as the text for an upper-division course on linear least squares and linear programming. Understanding is enhanced by numerous exercises.

A stand-alone textbook in matrix algebra for econometricians and statisticians - advanced undergraduates, postgraduates and teachers.

This book on linear algebra and geometry is based on a course given by renowned academician I.R. Shafarevich at Moscow State University. The book begins with the theory of linear algebraic equations and the basic elements of matrix theory and continues with vector spaces, linear transformations, inner product spaces, and the theory of affine and projective spaces. The book also includes some subjects that are naturally related to linear algebra but are usually not covered in such courses: exterior algebras, non-Euclidean geometry, topological properties of projective spaces, theory of quadrics (in affine and projective spaces), decomposition of finite abelian groups, and finitely generated periodic modules (similar to Jordan normal forms of linear operators). Mathematical reasoning, theorems, and concepts are

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illustrated with numerous examples from various fields of mathematics, including differential equations and differential geometry, as well as from mechanics and physics.

A groundbreaking introduction to vectors, matrices, and least squares for engineering applications, offering a wealth of practical examples.

Covers determinants, linear spaces, systems of linear equations, linear functions of a vector argument, coordinate transformations, the canonical form of the matrix of a linear operator, bilinear and quadratic forms, Euclidean spaces, unitary spaces, quadratic forms in Euclidean and unitary spaces, finite-dimensional space. Problems with hints and answers.

This accessible book for beginners uses intuitive geometric concepts to create abstract algebraic theory with a special emphasis on geometric characterizations. The book applies known results to describe various geometries and their invariants, and presents problems concerned with linear algebra, such as in real and complex analysis, differential equations, differentiable manifolds, differential geometry, Markov chains and transformation groups. The clear and inductive approach makes this book unique among existing books on linear algebra both in presentation and in content.

Grassmann Algebra Volume 1: Foundations Exploring extended vector algebra with  
Mathematica Grassmann algebra extends vector algebra by introducing the exterior product to algebraicize the notion of linear dependence. With it, vectors may be extended to higher-grade

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entities: bivectors, trivectors,  $\dots$  multivectors. The extensive exterior product also has a regressive dual: the regressive product. The pair behaves a little like the Boolean duals of union and intersection. By interpreting one of the elements of the vector space as an origin point, points can be defined, and the exterior product can extend points into higher-grade located entities from which lines, planes and multiplanes can be defined. Theorems of Projective Geometry are simply formulae involving these entities and the dual products. By introducing the (orthogonal) complement operation, the scalar product of vectors may be extended to the interior product of multivectors, which in this more general case may no longer result in a scalar. The notion of the magnitude of vectors is extended to the magnitude of multivectors: for example, the magnitude of the exterior product of two vectors (a bivector) is the area of the parallelogram formed by them. To develop these foundational concepts, we need only consider entities which are the sums of elements of the same grade. This is the focus of this volume. But the entities of Grassmann algebra need not be of the same grade, and the possible product types need not be constricted to just the exterior, regressive and interior products. For example quaternion algebra is simply the Grassmann algebra of scalars and bivectors under a new product operation. Clifford, geometric and higher order hypercomplex algebras, for example the octonions, may be defined similarly. If to these we introduce Clifford's invention of a scalar which squares to zero, we can define entities (for example dual quaternions) with which we can perform elaborate transformations. Exploration of these entities, operations and algebras will be the focus of the volume to follow this. There is something fascinating about the beauty with which the mathematical structures that Hermann Grassmann discovered describe the physical world, and something also fascinating about how

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these beautiful structures have been largely lost to the mainstreams of mathematics and science. He wrote his seminal *Ausdehnungslehre* (Die Ausdehnungslehre. Vollständig und in strenger Form) in 1862. But it was not until the latter part of his life that he received any significant recognition for it, most notably by Gibbs and Clifford. In recent times David Hestenes' *Geometric Algebra* must be given the credit for much of the emerging awareness of Grassmann's innovation. In the hope that the book be accessible to scientists and engineers, students and professionals alike, the text attempts to avoid any terminology which does not make an essential contribution to an understanding of the basic concepts. Some familiarity with basic linear algebra may however be useful. The book is written using Mathematica, a powerful system for doing mathematics on a computer. This enables the theory to be cross-checked with computational explorations. However, a knowledge of Mathematica is not essential for an appreciation of Grassmann's beautiful ideas.

This publication was made possible through a bequest from my beloved late wife. United together in this present collection are those works by the author which have not previously appeared in book form. The following are excepted: *Vorlesungen tiber Differential und Integralrechnung* (Lectures on Differential and Integral Calculus) Vols 1-3, Birkhiuser Verlag, Basel (1965-1968); *Aufgabensammlung zur Infinitesimalrechnung* (Exercises in Infinitesimal Calculus) Vols 1, 2a, 2b, and 3, Birkhiuser Verlag, Basel (1967-1977); two issues from *Memorial des Sciences on Conformal Mapping* (written together with C. Gattegno), Gauthier-Villars, Paris (1949); *Solution of Equations in Euclidean and Banach Spaces*, Academic Press, New York (1973); and *Stu dien tiber den Schottkyschen Satz* (Studies on Schottky's Theorem),

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Wepf & Co., Basel (1931). Where corrections have had to be implemented in the text of certain papers, references to these are made at the conclusion of each paper. In the few instances where this system does not, for technical reasons, seem appropriate, an asterisk in the page margin indicates wherever a correction is necessary and this is then given at the end of the paper. (There is one exception: the corrections to the paper on page 561 are presented on page 722. The works are published in 6 volumes and are arranged under 16 topic headings. Within each heading, the papers are ordered chronologically according to the date of original publication.

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