

# Fractional

**Boris Rubin**

Fractional Differential Equations Igor Podlubny,1998-10-27 This book is a landmark title in the continuous move from integer to non-integer in mathematics: from integer numbers to real numbers, from factorials to the gamma function, from integer-order models to models of an arbitrary order. For historical reasons, the word 'fractional' is used instead of the word 'arbitrary'. This book is written for readers who are new to the fields of fractional derivatives and fractional-order mathematical models, and feel that they need them for developing more adequate mathematical models. In this book, not only applied scientists, but also pure mathematicians will find fresh motivation for developing new methods and approaches in their fields of research. A reader will find in this book everything necessary for the initial study and immediate application of fractional derivatives fractional differential equations, including several necessary special functions, basic theory of fractional differentiation, uniqueness and existence theorems, analytical numerical methods of solution of fractional differential equations, and many inspiring examples of applications. A unique survey of many applications of fractional calculus Presents basic theory Includes a unified presentation of selected classical results, which are important for applications Provides many examples Contains a separate chapter of fractional order control systems, which opens new perspectives in control theory The first systematic consideration of Caputo's fractional derivative in comparison with other selected approaches Includes tables of fractional derivatives, which can be used for evaluation of all considered types of fractional derivatives

**Fractional Calculus** Herrmann Richard,2001-02-12 The book presents a concise introduction to the basic methods and strategies in fractional calculus which enables the reader to catch up with the state-of-the-art in this field and to participate and contribute in the development of this exciting research area. This book is devoted to the application of fractional calculus on physical problems. The fractional concept is applied to subjects in classical mechanics, image processing, folded potentials in cluster physics, infrared spectroscopy, group theory, quantum mechanics, nuclear physics, hadron spectroscopy up to quantum field theory and will surprise the reader with new intriguing insights. This new, extended edition includes additional chapters about numerical solution of the fractional Schrödinger equation, self-similarity and the geometric interpretation of non-isotropic fractional differential operators. Motivated by the positive response, new exercises with elaborated solutions are added, which significantly support a deeper understanding of the general aspects of the theory. Besides students as well as researchers in this field, this book will also be useful as a supporting medium for teachers teaching courses devoted to this subject.

**Children's Fractional Knowledge** Leslie P. Steffe,John Olive,2009-12-02 Children's Fractional Knowledge elegantly tracks the construction of knowledge, both by children learning new methods of reasoning and by the researchers studying their methods. The book challenges the widely held belief that children's whole number knowledge is a distraction from their learning of fractions by positing that their fractional learning involves reorganizing—not simply using or building upon—their whole number knowledge. This hypothesis is explained in detail using examples of actual grade-schoolers approaching problems in fractions including the schemes they construct to relate parts to a whole, to produce a fraction as a multiple of a unit part, to transform a fraction into a commensurate fraction, or to combine two fractions multiplicatively or additively. These case studies provide a singular journey into children's mathematics experience, which often varies greatly from that of adults. Moreover, the authors' descriptive terms reflect children's quantitative operations, as opposed to adult mathematical phrases rooted in concepts that do not reflect—and which in the classroom may even suppress—youngsters' learning experiences. Highlights of the coverage: Toward a formulation of a mathematics of living instead of being Operations that produce numerical counting schemes Case studies: children's part-whole, partitive, iterative, and other fraction schemes Using the generalized number sequence to produce fraction schemes Redefining school mathematics This fresh perspective is of immediate importance to researchers in mathematics education. With the up-close lens onto mathematical development found in Children's Fractional Knowledge, readers can work toward creating more effective methods for improving young learners' quantitative reasoning skills.

*The Fractional Trigonometry* Carl F. Lorenzo,Tom T. Hartley,2016-11-14 Addresses the rapidly growing field of fractional calculus and provides simplified solutions for linear commensurate-order fractional differential equations The Fractional Trigonometry: With Applications to Fractional Differential Equations and Science is the result of the authors' work in fractional calculus, and more particularly, in functions for the solutions of fractional differential equations, which is fostered in the behavior of generalized exponential functions. The authors discuss how fractional trigonometry plays a role analogous to the classical trigonometry for the fractional calculus by providing solutions to linear fractional differential equations. The book begins with an introductory chapter that offers insight into the fundamentals of fractional calculus, and topical coverage is then organized in two main parts. Part One develops the definitions and theories of fractional exponentials and fractional trigonometry. Part Two provides insight into various areas of potential application within the sciences. The fractional exponential function via the fundamental fractional differential equation, the generalized exponential function, and R-function relationships are discussed in addition to the fractional hyperboletry, the R1-fractional trigonometry, the R2-fractional trigonometry, and the R3-trigonometric functions. The Fractional Trigonometry: With Applications to Fractional Differential Equations and Science also: Presents fractional trigonometry as a tool for scientists and engineers and discusses how to apply fractional-order methods to the current toolbox of mathematical modelers Employs a mathematically clear presentation in an effort to make the topic broadly accessible Includes solutions to linear fractional differential equations and generously features graphical forms of functions to help readers visualize the presented concepts Provides effective and efficient methods to describe complex structures The Fractional Trigonometry: With Applications to Fractional Differential Equations and Science is an ideal reference for academic researchers, research engineers, research scientists, mathematicians, physicists, biologists, and chemists who need to apply new fractional calculus methods to a variety of disciplines. The book is also appropriate as a textbook for graduate- and PhD-level courses in fractional calculus. Carl F. Lorenzo is Distinguished Research Associate at the NASA Glenn Research Center in Cleveland, Ohio. His past positions include chief engineer of the Instrumentation and Controls Division and chief of the Advanced Controls Technology and Systems Dynamics branches at NASA. He is internationally recognized for his work in the development and application of the fractional calculus and fractional trigonometry. Tom T. Hartley, PhD, is Emeritus Professor in the Department of Electrical and Computer Engineering at The University of Akron. Dr Hartley is a recognized expert in fractional-order systems, and together with Carl Lorenzo, has solved fundamental problems in the area including Riemann's complementary-function initialization function problem. He received his PhD in Electrical Engineering from Vanderbilt University.

**Introduction to the Fractional Calculus of Variations** Agnieszka B Malinowska,Delfim F M Torres,2012-09-14 This invaluable book provides a broad introduction to the fascinating and beautiful subject of Fractional Calculus of Variations (FCV). In 1996, FVC evolved in order to better describe non-conservative systems in mechanics. The inclusion of non-conservatism is extremely important from the point of view of applications. Forces that do not store energy are always present in real systems. They remove energy from the systems and, as a consequence, Noether's conservation laws cease to be valid. However, it is still possible to obtain the validity of Noether's principle using FCV. The new theory provides a more realistic approach to physics, allowing us to consider non-conservative systems in a natural way. The authors prove the necessary Euler-Lagrange conditions and corresponding Noether theorems for several types of fractional variational problems, with and without constraints, using Lagrangian and Hamiltonian formalisms. Sufficient optimality conditions are also obtained under convexity, and Leitmann's direct method is discussed within the framework of FCV. The book is self-contained and unified in presentation. It may be used as an advanced textbook by graduate students and ambitious undergraduates in mathematics and mechanics. It provides an opportunity for an introduction to FCV for experienced researchers. The explanations in the book are detailed, in order to capture the interest of the curious reader, and the book provides the necessary background material required to go further into the subject and explore the rich research literature.

Small Fractional Parts of Polynomials Wolfgang M. Schmidt,1977 Knowledge about fractional parts of linear polynomials is fairly satisfactory. Knowledge about fractional parts of nonlinear polynomials is not so satisfactory. In these notes the author starts out with Heilbronn's Theorem on quadratic polynomials and branches out in three directions. In Sections 7-12 he deals with arbitrary polynomials with constant term zero. In Sections 13-19 he takes up simultaneous approximation of quadratic polynomials. In Sections 20-21 he discusses special quadratic polynomials in several variables. There are many open questions: in fact, most of the results obtained in these notes are almost certainly not best possible. Since the theory is not in its final form including the most general situation, i.e. simultaneous fractional parts of polynomials in several variables of

arbitrary degree. On the other hand, he has given all proofs in full detail and at a leisurely pace. For the first half of this work, only the standard notions of an undergraduate number theory course are required. For the second half, some knowledge of the geometry of numbers is helpful.

**Fractional Graph Theory** Edward R. Scheinerman, Daniel H. Ullman, 2013-04-29 This volume explains the general theory of hypergraphs and presents in-depth coverage of fundamental and advanced topics: fractional matching, fractional coloring, fractional edge coloring, fractional arboricity via matroid methods, fractional isomorphism, and more. 1997 edition.

**Fractional Calculus** Varsha Daftardar-Gejji, 2013-07-26 FRACTIONAL CALCULUS: Theory and Applications deals with differentiation and integration of arbitrary order. The origin of this subject can be traced back to the end of seventeenth century, the time when Newton and Leibniz developed foundations of differential and integral calculus. Nonetheless, utility and applicability of FC to various branches of science and engineering have been realized only in last few decades. Recent years have witnessed tremendous upsurge in research activities related to the applications of FC in modeling of real-world systems. Unlike the derivatives of integral order, the non-local nature of fractional derivatives correctly models many natural phenomena containing long memory and give more accurate description than their integer counterparts. The present book comprises of contributions from academicians and leading researchers and gives a panoramic overview of various aspects of this subject: Introduction to Fractional Calculus Fractional Differential Equations Fractional Ordered Dynamical Systems Fractional Operators on Fractals Local Fractional Derivatives Fractional Control Systems Fractional Operators and Statistical Distributions Applications to Engineering

The Fractional Laplacian Wenxiong Chen, Yan Li, Pei Ma, 2020-06-09 This is a unique book that provides a comprehensive understanding of nonlinear equations involving the fractional Laplacian as well as other nonlocal operators. Beginning from the definition of fractional Laplacian, it gradually leads the readers to the frontier of current research in this area. The explanations and illustrations are elementary enough so that first year graduate students can follow easily, while it is advanced enough to include many new ideas, methods, and results that appeared recently in research literature, which researchers would find helpful. It focuses on introducing direct methods on the nonlocal problems without going through extensions, such as the direct methods of moving planes, direct method of moving spheres, direct blowing up and rescaling arguments, and so on. Different from most other books, it emphasizes on illuminating the ideas behind the formal concepts and proofs, so that readers can quickly grasp the essence.

**Generalized Fractional Calculus and Applications** Virginia S Kiryakova, 1993-12-27 In this volume various applications are discussed, in particular to the hyper-Bessel differential operators and equations, Dzrbashjan-Gelfond-Leontiev operators and Borel type transforms, convolutions, new representations of hypergeometric functions, solutions to classes of differential and integral equations, transmutation method, and generalized integral transforms. Some open problems are also posed. This book is intended for graduate and post-graduate students, lecturers, researchers and others working in applied mathematical analysis, mathematical physics and related disciplines.

*Functional Fractional Calculus* Shantanu Das, 2011-06-01 When a new extraordinary and outstanding theory is stated, it has to face criticism and skepticism, because it is beyond the usual concept. The fractional calculus though not new, was not discussed or developed for a long time, particularly for lack of its application to real life problems. It is extraordinary because it does not deal with 'ordinary' differential calculus. It is outstanding because it can now be applied to situations where existing theories fail to give satisfactory results. In this book not only mathematical abstractions are discussed in a lucid manner, with physical mathematical and geometrical explanations, but also several practical applications are given particularly for system identification, description and then efficient controls. The normal physical laws like, transport theory, electrodynamics, equation of motions, elasticity, viscosity, and several others of are based on 'ordinary' calculus. In this book these physical laws are generalized in fractional calculus contexts; taking, heterogeneity effect in transport background, the space having traps or islands, irregular distribution of charges, non-ideal spring with mass connected to a pointless-mass ball, material behaving with viscous as well as elastic properties, system relaxation with and without memory, physics of random delay in computer network; and several others; mapping the reality of nature closely. The concept of fractional and complex order differentiation and integration are elaborated mathematically, physically and geometrically with examples. The practical utility of local fractional differentiation for enhancing the character of singularity at phase transition or characterizing the irregularity measure of response function is deliberated. Practical results of viscoelastic experiments, fractional order controls experiments, design of fractional controller and practical circuit synthesis for fractional order elements are elaborated in this book. The book also maps theory of classical integer order differential equations to fractional calculus contexts, and deals in details with conflicting and demanding initialization issues, required in classical techniques. The book presents a modern approach to solve the 'solvable' system of fractional and other differential equations, linear, non-linear; without perturbation or transformations, but by applying physical principle of action-and-opposite-reaction, giving 'approximately exact' series solutions. Historically, Sir Isaac Newton and Gottfried Wilhelm Leibniz independently discovered calculus in the middle of the 17th century. In recognition to this remarkable discovery, J.von Neumann remarked, "...the calculus was the first achievement of modern mathematics and it is difficult to overestimate its importance. I think it defines more equivocally than anything else the inception of modern mathematical analysis which is logical development, still constitute the greatest technical advance in exact thinking." This XXI century has thus started to 'think-exactly' for advancement in science & technology by growing application of fractional calculus, and this century has started speaking the language which nature understands the best.

**Fractional Integrals and Derivatives** Stefan Samko, Anatoly A. Kilbas, Oleg Marichev, 1993-12-08 In San Francisco, a fisherman's get-rich-quick scheme ends in violence. As sharks fetch high prices, he hires a professional shark hunter to go fishing, the deal being he gets the first three tons, the hunter the rest. But as the hunter's share piles up, jealousy rears its head.

Fractional Calculus and Fractional Processes with Applications to Financial Economics Hasan Fallahgoul, Sergio Focardi, Frank Fabozzi, 2016-10-06 Fractional Calculus and Fractional Processes with Applications to Financial Economics presents the theory and application of fractional calculus and fractional processes to financial data. Fractional calculus dates back to 1695 when Gottfried Wilhelm Leibniz first suggested the possibility of fractional derivatives. Research on fractional calculus started in full earnest in the second half of the twentieth century. The fractional paradigm applies not only to calculus, but also to stochastic processes, used in many applications in financial economics such as modelling volatility, interest rates, and modelling high-frequency data. The key features of fractional processes that make them interesting are long-range memory, path-dependence, non-Markovian properties, self-similarity, fractal paths, and anomalous diffusion behaviour. In this book, the authors discuss how fractional calculus and fractional processes are used in financial modelling and finance economic theory. It provides a practical guide that can be useful for students, researchers, and quantitative asset and risk managers interested in applying fractional calculus and fractional processes to asset pricing, financial time-series analysis, stochastic volatility modelling, and portfolio optimization. Provides the necessary background for the book's content as applied to financial economics Analyzes the application of fractional calculus and fractional processes from deterministic and stochastic perspectives

*Stochastic Calculus for Fractional Brownian Motion and Related Processes* Yuliya Mishura, Iuliia S. Mishura, 2008-01-02 This volume examines the theory of fractional Brownian motion and other long-memory processes. Interesting topics for PhD students and specialists in probability theory, stochastic analysis and financial mathematics demonstrate the modern level of this field. It proves that the market with stock guided by the mixed model is arbitrage-free without any restriction on the dependence of the components and deduces different forms of the Black-Scholes equation for fractional market.

Theory And Applications of Fractional Differential Equations A. Anatolii Aleksandrovich Kilbas, Hari Mohan Srivastava, Juan J. Trujillo, 2006 This monograph provides the most recent and up-to-date developments on fractional differential and fractional integro-differential equations involving many different potentially useful operators of fractional calculus. The subject of fractional calculus and its applications (that is, calculus of integrals and derivatives of any arbitrary real or complex order) has gained considerable popularity and importance during the past three decades or so, due mainly to its demonstrated applications in numerous seemingly diverse and widespread fields of science and engineering. Some of the areas of present-day applications of fractional models include Fluid Flow, Solute Transport or Dynamical Processes in Self-Similar and Porous

Structures, Diffusive Transport akin to Diffusion, Material Viscoelastic Theory, Electromagnetic Theory, Dynamics of Earthquakes, Control Theory of Dynamical Systems, Optics and Signal Processing, Bio-Sciences, Economics, Geology, Astrophysics, Probability and Statistics, Chemical Physics, and so on. In the above-mentioned areas, there are phenomena with strange kinetics which have a microscopic complex behaviour, and their macroscopic dynamics can not be characterized by classical derivative models. The fractional modelling is an emergent tool which use fractional differential equations including derivatives of fractional order, that is, we can speak about a derivative of order  $1/3$ , or square root of 2, and so on. Some of such fractional models can have solutions which are non-differentiable but continuous functions, such as Weierstrass type functions. Such kinds of properties are, obviously, impossible for the ordinary models. What are the useful properties of these fractional operators which help in the modelling of so many anomalous processes? From the point of view of the authors and from known experimental results, most of the processes associated with complex systems have non-local dynamics involving long-memory in time, and the fractional integral and fractional derivative operators do have some of those characteristics. This book is written primarily for the graduate students and researchers in many different disciplines in the mathematical, physical, engineering and so many others sciences, who are interested not only in learning about the various mathematical tools and techniques used in the theory and widespread applications of fractional differential equations, but also in further investigations which emerge naturally from (or which are motivated substantially by) the physical situations modelled mathematically in the book. This monograph consists of a total of eight chapters and a very extensive bibliography. The main objective of it is to complement the contents of the other books dedicated to the study and the applications of fractional differential equations. The aim of the book is to present, in a systematic manner, results including the existence and uniqueness of solutions for the Cauchy type problems involving nonlinear ordinary fractional differential equations, explicit solutions of linear differential equations and of the corresponding initial-value problems through different methods, closed-form solutions of ordinary and partial differential equations, and a theory of the so-called sequential linear fractional differential equations including a generalization of the classical Frobenius method, and also to include an interesting set of applications of the developed theory. Key features: - It is mainly application oriented. - It contains a complete theory of Fractional Differential Equations. - It can be used as a postgraduate-level textbook in many different disciplines within science and engineering. - It contains an up-to-date bibliography. - It provides problems and directions for further investigations. - Fractional Modelling is an emergent tool with demonstrated applications in numerous seemingly diverse and widespread fields of science and engineering. - It contains many examples. - and so on!

**Discrete Fractional Calculus** Christopher Goodrich, Allan C. Peterson, 2016-02-09 This text provides the first comprehensive treatment of the discrete fractional calculus. Experienced researchers will find the text useful as a reference for discrete fractional calculus and topics of current interest. Students who are interested in learning about discrete fractional calculus will find this text to provide a useful starting point. Several exercises are offered at the end of each chapter and select answers have been provided at the end of the book. The presentation of the content is designed to give ample flexibility for potential use in a myriad of courses and for independent study. The novel approach taken by the authors includes a simultaneous treatment of the fractional- and integer-order difference calculus (on a variety of time scales, including both the usual forward and backwards difference operators). The reader will acquire a solid foundation in the classical topics of the discrete calculus while being introduced to exciting recent developments, bringing them to the frontiers of the subject. Most chapters may be covered or omitted, depending upon the background of the student. For example, the text may be used as a primary reference in an introductory course for difference equations which also includes discrete fractional calculus. Chapters 1—2 provide a basic introduction to the delta calculus including fractional calculus on the set of integers. For courses where students already have background in elementary real analysis, Chapters 1—2 may be covered quickly and readers may then skip to Chapters 6—7 which present some basic results in fractional boundary value problems (FBVPs). Chapters 6—7 in conjunction with some of the current literature listed in the Bibliography can provide a basis for a seminar in the current theory of FBVPs. For a two-semester course, Chapters 1—5 may be covered in depth, providing a very thorough introduction to both the discrete fractional calculus as well as the integer-order calculus.

**Fractional Dynamics** Joseph Klafter, S. C. Lim, Ralf Metzler, 2012 This volume provides the latest developments in the field of fractional dynamics, which covers fractional (anomalous) transport phenomena, fractional statistical mechanics, fractional quantum mechanics and fractional quantum field theory. The contributors are selected based on their active and important contributions to their respective topics. This volume is the first of its kind that covers such a comprehensive range of topics in fractional dynamics. It will point out to advanced undergraduate and graduate students, and young researchers the possible directions of research in this subject. In addition to those who intend to work in this field and those already in the field, this volume will also be useful for researchers not directly involved in the field, but want to know the current status and trends of development in this subject. This latter group includes theoretical chemists, mathematical biologists and engineers.

**Fractional Integrals and Potentials** Boris Rubin, 1996-06-24 This volume presents recent developments in the fractional calculus of functions of one and several real variables, and shows the relation of this field to a variety of areas in pure and applied mathematics. Beyond some basic properties of fractional integrals in one and many dimensions, it contains a mathematical theory of certain important weakly singular integral equations of the first kind arising in mechanics, diffraction theory and other areas of mathematical physics. The author focuses on explicit inversion formulae that can be obtained by making use of the classical Marchaud's approach and its generalization, leading to wavelet type representations.

**Applications Of Fractional Calculus In Physics** Rudolf Hilfer, 2000-03-02 Fractional calculus is a collection of relatively little-known mathematical results concerning generalizations of differentiation and integration to noninteger orders. While these results have been accumulated over centuries in various branches of mathematics, they have until recently found little appreciation or application in physics and other mathematically oriented sciences. This situation is beginning to change, and there are now a growing number of research areas in physics which employ fractional calculus. This volume provides an introduction to fractional calculus for physicists, and collects easily accessible review articles surveying those areas of physics in which applications of fractional calculus have recently become prominent.

**Kindergarten of Fractional Calculus** Shantanu Das, 2020-02-18 This book presents a simplified deliberation of fractional calculus, which will appeal not only to beginners, but also to various applied science mathematicians and engineering researchers. The text develops the ideas behind this new field of mathematics, beginning at the most elementary level, before discussing its actual applications in different areas of science and engineering. This book shows that the simple, classical laws based on Newtonian calculus, which work quite well under limiting and idealized conditions, are not of much use in describing the dynamics of actual systems. As such, the application of non-Newtonian, or generalized, calculus in the governing equations, allows the order of differentiation and integration to take on non-integer values.

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Table of Contents Fractional

	◦ Integration of Multimedia Elements
	◦ Interactive and Gamified eBooks
1. Understanding the eBook Fractional	
◦	The Rise of Digital Reading Fractional
◦	Advantages of eBooks Over Traditional Books
2. Identifying Fractional	
◦	Exploring Different Genres
◦	Considering Fiction vs. Non-Fiction
◦	Determining Your Reading Goals
3. Choosing the Right eBook Platform	
◦	Popular eBook Platforms
◦	Features to Look for in an Fractional
◦	User-Friendly Interface
4. Exploring eBook Recommendations from Fractional	
◦	Personalized Recommendations
◦	Fractional User Reviews and Ratings
◦	Fractional and Bestseller Lists
5. Accessing Fractional Free and Paid eBooks	
◦	Fractional Public Domain eBooks
◦	Fractional eBook Subscription Services
◦	Fractional Budget-Friendly Options
6. Navigating Fractional eBook Formats	
◦	ePub, PDF, MOBI, and More
◦	Fractional Compatibility with Devices
◦	Fractional Enhanced eBook Features
7. Enhancing Your Reading Experience	
◦	Adjustable Fonts and Text Sizes of Fractional
◦	Highlighting and Note-Taking Fractional
◦	Interactive Elements Fractional
8. Staying Engaged with Fractional	
◦	Joining Online Reading Communities
◦	Participating in Virtual Book Clubs
◦	Following Authors and Publishers Fractional
9. Balancing eBooks and Physical Books Fractional	
◦	Benefits of a Digital Library
◦	Creating a Diverse Reading Collection Fractional
10. Overcoming Reading Challenges	
◦	Dealing with Digital Eye Strain
◦	Minimizing Distractions
◦	Managing Screen Time
11. Cultivating a Reading Routine Fractional	
◦	Setting Reading Goals Fractional
◦	Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Fractional	
◦	Fact-Checking eBook Content of Fractional
◦	Distinguishing Credible Sources
13. Promoting Lifelong Learning	
◦	Utilizing eBooks for Skill Development
◦	Exploring Educational eBooks
14. Embracing eBook Trends	

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