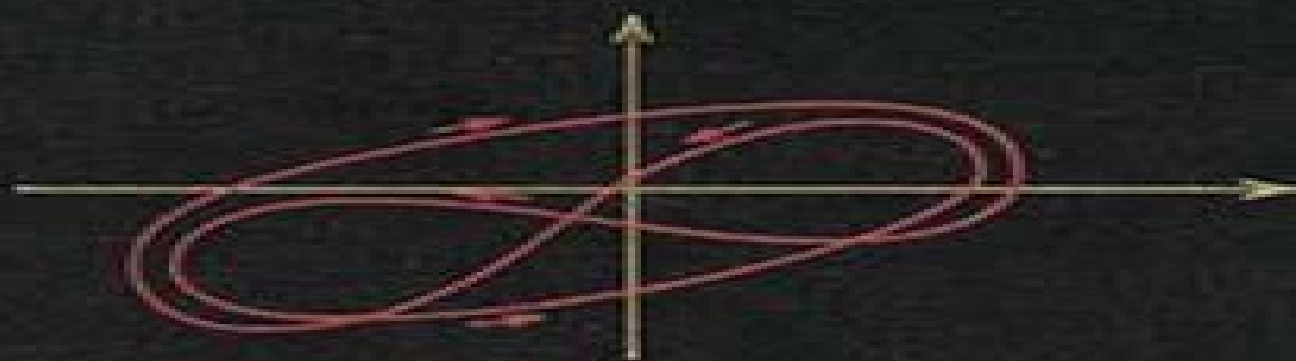


# **AN INTRODUCTION TO THE FRACTIONAL CALCULUS AND FRACTIONAL DIFFERENTIAL EQUATIONS**



**KENNETH S. MILLER  
BERTRAM ROSS**

# An Introduction To The Fractional Calculus And Fractional Differential Equations

**Saïd Abbas, Mouffak Benchohra, Gaston  
M. N'Guérékata**



## **An Introduction To The Fractional Calculus And Fractional Differential Equations:**

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

**Time-Fractional Differential Equations** Adam Kubica, Katarzyna Ryszewska, Masahiro Yamamoto, 2020-11-29 This book aims to establish a foundation for fractional derivatives and fractional differential equations The theory of fractional derivatives enables considering any positive order of differentiation The history of research in this field is very long with its origins dating back to Leibniz Since then many great mathematicians such as Abel have made contributions that cover not only theoretical aspects but also physical applications of fractional calculus The fractional partial differential equations govern phenomena depending both on spatial and time variables and require more subtle treatments Moreover fractional partial differential equations are highly demanded model equations for solving real world problems such as the anomalous diffusion in heterogeneous media The studies of fractional partial differential equations have continued to expand explosively However we observe that available mathematical theory for fractional partial differential equations is not still complete In particular operator theoretical approaches are indispensable for some generalized categories of solutions such as weak solutions but feasible operator theoretic foundations for wide applications are not available in monographs To make this monograph more readable we are restricting it to a few fundamental types of time fractional partial differential equations forgoing many other important and exciting topics such as stability for nonlinear problems However we believe that this book works well as an introduction to mathematical research in such vast fields

**An Introduction to the Fractional Calculus and Fractional Differential Equations** Kenneth S. Miller, Bertram Ross, 1993-06-02 Commences with the historical

development of fractional calculus its mathematical theory particularly the Riemann Liouville version Numerous examples and theoretical applications of the theory are presented Features topics associated with fractional differential equations Discusses Weyl fractional calculus and some of its uses Includes selected physical problems which lead to fractional differential or integral equations *Introduction To The Fractional Calculus Of Variations* Delfim F M Torres, Agnieszka Barbara Malinowska, 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 a [Introduction to Fractional Differential Equations](#) Constantin Milici, Gheorghe Drăgănescu, J. Tenreiro Machado, 2018-10-28 This book introduces a series of problems and methods insufficiently discussed in the field of Fractional Calculus a major emerging tool relevant to all areas of scientific inquiry The authors present examples based on symbolic computation written in Maple and Mathematica and address both mathematical and computational areas in the context of mathematical modeling and the generalization of classical integer order methods Distinct from most books the present volume fills the gap between mathematics and computer fields and the transition from integer to fractional order methods

**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

**Fractional Calculus and Fractional Differential Equations** Varsha Daftardar-Gejji, 2019-08-10 This book provides a broad overview of the latest developments in fractional calculus and fractional differential equations FDEs with an aim to motivate the readers to venture into these areas It also presents original research describing the fractional operators of variable order fractional order delay differential equations chaos and related phenomena in detail Selected results on the stability of solutions of nonlinear dynamical systems of the non commensurate fractional order have also been included Furthermore artificial neural network and fractional differential equations are elaborated on and new transform methods for example Sumudu methods and how they can be employed to solve fractional partial differential equations are discussed The book covers the latest research on a variety of topics including comparison of various numerical methods for solving FDEs the Adomian decomposition method and its applications to fractional versions of the classical Poisson processes variable order fractional operators fractional variational principles fractional delay differential equations fractional order dynamical systems and stability analysis inequalities and comparison theorems in FDEs artificial neural network approximation for fractional operators and new transform methods for solving partial FDEs Given its scope and level of detail the book will be an invaluable asset for researchers working in these areas

**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 Differential Equations** Zhi-Zhong Sun, Guang-hua Gao, 2020-08-24 Starting with an introduction to fractional derivatives and numerical approximations this book presents finite difference methods for fractional differential equations including time fractional sub diffusion equations time fractional wave equations and space fractional differential equations among others Approximation methods for fractional derivatives are developed and approximate accuracies are analyzed in detail [Computational Methods In The Fractional Calculus Of Variations](#) Ricardo Almeida, Shakoor Pooseh, Delfim F M Torres, 2015-03-19 This book fills a gap in the literature by introducing numerical techniques to solve problems of fractional calculus of variations FCV In most cases finding the analytic solution to such problems is extremely difficult or even impossible and numerical methods need to be used The authors are well known researchers in the area of FCV and the book contains some of their recent results serving as a companion volume to Introduction to the Fractional Calculus of Variations by A B Malinowska and D F M Torres where analytical methods are presented to solve FCV problems After some preliminaries on the subject different techniques are presented in detail with numerous examples to help the reader to better understand the methods The techniques presented may be used not only to deal with FCV problems but also in other contexts of fractional calculus such as fractional differential equations and fractional optimal control It is suitable as an advanced book for graduate students in mathematics physics and engineering as well as for researchers interested in fractional calculus **An Introduction to Fractional Differential Equations** K. Balachandran, 2023-11-23 This is an introductory level text on fractional calculus and fractional differential equations Targeted to graduate students of mathematics and researchers it contains several new definitions of fractional integrals and fractional derivatives With interesting applications of the subject in several areas of physical sciences life sciences engineering and technology the book

helps the students understand the importance and developments of this topic The book is enriched with a list of useful references to published literature and the presentation of the book is entirely new and easily comprehensible to the students Some of the topics are refined and new examples are included to supplement theories to help students understand the concepts easily and clearly      **Topics in Fractional Differential Equations** Saïd Abbas,Mouffak Benchohra,Gaston M.

N'Guérékata,2012-08-17 Topics in Fractional Differential Equations is devoted to the existence and uniqueness of solutions for various classes of Darboux problems for hyperbolic differential equations or inclusions involving the Caputo fractional derivative Fractional calculus generalizes the integrals and derivatives to non integer orders During the last decade fractional calculus was found to play a fundamental role in the modeling of a considerable number of phenomena in particular the modeling of memory dependent and complex media such as porous media It has emerged as an important tool for the study of dynamical systems where classical methods reveal strong limitations Some equations present delays which may be finite infinite or state dependent Others are subject to an impulsive effect The above problems are studied using the fixed point approach the method of upper and lower solution and the Kuratowski measure of noncompactness This book is addressed to a wide audience of specialists such as mathematicians engineers biologists and physicists      *Fractional*

*Differential Equations* Bangti Jin,2021-07-22 This graduate textbook provides a self contained introduction to modern mathematical theory on fractional differential equations It addresses both ordinary and partial differential equations with a focus on detailed solution theory especially regularity theory under realistic assumptions on the problem data The text includes an extensive bibliography application driven modeling extensive exercises and graphic illustrations throughout to complement its comprehensive presentation of the field It is recommended for graduate students and researchers in applied and computational mathematics particularly applied analysis numerical analysis and inverse problems      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      *Basic Theory Of Fractional Differential Equations*

*(Second Edition)* Yong Zhou,Jinrong Wang,Lu Zhang,2016-10-20 This invaluable monograph is devoted to a rapidly developing area on the research of qualitative theory of fractional ordinary and partial differential equations It provides the readers the necessary background material required to go further into the subject and explore the rich research literature The tools used include many classical and modern nonlinear analysis methods such as fixed point theory measure of

noncompactness method topological degree method the technique of Picard operators critical point theory and semigroup theory Based on the research work carried out by the authors and other experts during the past seven years the contents are very recent and comprehensive In this edition two new topics have been added that is fractional impulsive differential equations and fractional partial differential equations including fractional Navier Stokes equations and fractional diffusion equations

**Basic Theory Of Fractional Differential Equations (Third Edition)** Yong Zhou,2023-10-06 This accessible monograph is devoted to a rapidly developing area on the research of qualitative theory of fractional ordinary differential equations and evolution equations It is self contained and unified in presentation and provides the readers the necessary background material required to go further into the subject and explore the rich research literature The tools used include many classical and modern nonlinear analysis methods such as fixed point theory measure of noncompactness method topological degree method Picard operators technique critical point theory and semigroups theory This book is based on the research work done so far by the author and other experts and contains comprehensive up to date materials on the topic In this third edition four new topics have been added Hilfer fractional evolution equations and infinite interval problems oscillations and nonoscillations fractional Hamiltonian systems fractional Rayleigh Stokes equations and wave equations The bibliography has also been updated and expanded This book is useful to researchers graduate or PhD students dealing with fractional calculus and applied analysis differential equations and related areas of research

**Fractional Integrals and Derivatives: "True" versus "False"** Yuri Luchko,2021-03-16 This Special Issue is devoted to some serious problems that the Fractional Calculus FC is currently confronted with and aims at providing some answers to the questions like What are the fractional integrals and derivatives What are their decisive mathematical properties What fractional operators make sense in applications and why etc In particular the new fractional derivatives and integrals and the models with these fractional order operators are critically addressed The Special Issue contains both the surveys and the research contributions A part of the articles deals with foundations of FC that are considered from the viewpoints of the pure and applied mathematics and the system theory Another part of the Special issue addresses the applications of the FC operators and the fractional differential equations Several articles devoted to the numerical treatment of the FC operators and the fractional differential equations complete the Special Issue

*POCKET GUIDE FRACTIONAL DIFFERENTIAL EQUATION A QUICK GUIDE TO CONCEPTS AND SOLUTIONS* MS. GAZALA PERWEEN,DR. SMITA PATI, Pocket Guide Fractional Differential Equations provides an understandable introduction to fractional calculus and its uses In order to help readers understand complicated systems that contain memory and non local effects this pocket book fills a gap between the established discipline of fractional calculus and classical differential equations Regardless of your background student researcher or just interested in complex mathematics this book offers insightful information on a constantly expanding field of modern mathematics

Fractional Calculus and its Applications in Physics Dumitru Baleanu,Devendra Kumar,2019-11-15      *Fractional*



*Calculus: An Introduction For Physicists (Third Edition)* Richard Herrmann, 2018-07-09 The third edition of this book is designed to carefully and coherently introduce fractional calculus to physicists by applying the ideas to two distinct applications: classical problems and multi particle quantum problems. There remain many open questions and the field remains an active area of research. Dr. Herrmann's book is an excellent introduction to this field of study. Contemporary Physics: 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.

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