Progress in Nonlinear Differential Equations
and Their Applications

Michael Beals

Propagation and Interaction of Singularities in Nonlinear Hyperbolic Problems

Birkhäuser

Propagation And Interaction Of Singularities In Nonlinear Hyperbolic Problems

Jeffrey Rauch

Propagation And Interaction Of Singularities In Nonlinear Hyperbolic Problems:

Propagation and Interaction of Singularities in Nonlinear Hyperbolic Problems Michael Beals,2012-12-06 This book developed from a series of lectures I gave at the Symposium on Nonlinear Microlocal Analysis held at Nanjing University in October 1988 Its purpose is to give an overview of the use of microlocal analysis and commutators in the study of solutions to nonlinear wave equations The weak singularities in the solutions to such equations behave up to a certain extent like those present in the linear case they propagate along the null bicharacteristics of the operator On the other hand examples exhibiting singularities not present in the linear case can also be constructed I have tried to present a crossection of both the regularity results and the singular examples for problems on the interior of a domain and on domains with boundary The main emphasis is on the case of more than one space dimen sion since that case is treated in great detail in the paper of Rauch Reed 159 The results presented here have for the most part appeared elsewhere and are the work of many authors but a few new examples and proofs are given I have attempted to indicate the essential ideas behind the arguments so that only some of the results are proved in full detail It is hoped that the central notions of the more technical proofs appearing in research papers will be illuminated by these simpler cases **Nonlinear Hyperbolic Equations and Field Theory** M K V Murthy,S Spagnolo,1992-03-30 Contains the proceedings of a workshop on nonlinear hyperbolic equations held at Varenna Italy in June 1990 Symbolic Calculus Semilinear Hyperbolic Progressing Waves Hassane Bougrini,Alain Piriou,2000 The main purpose of this book is to give a self contained synthesis of different results in the domain of symbolic calculus of conormal singularities of semilinear hyperbolic progressing waves The authors deal generally with real matrix valued co efficients and with real vector valued solutions but the complex case is similar They consider also N x N first order systems rather than high order scalar equations because the polarisation properties of symbols are less natural in the latter case Moreover although they assume generally that the real characteristics are simple the methods can give results for symmetric or symmetrisable first order hyperbolic systems **Hyperbolic Equations and Frequency Interactions** Luis A. Caffarelli,Weinan E,1999 The research topic for this IAS PCMS Summer Session was nonlinear wave phenomena Mathematicians from the more theoretical areas of PDEs were brought together with those involved in applications The goal was to share ideas knowledge and perspectives How waves or frequencies interact in nonlinear phenomena has been a central issue in many of the recent developments in pure and applied analysis It is believed that wavelet theory with its simultaneous localization in both physical and frequency space and its lacunarity is and will be a fundamental new tool in the treatment of the phenomena Included in this volume are write ups of the general methods and tools courses held by Jeff Rauch and Ingrid Daubechies Rauch s article discusses geometric optics as an asymptotic limit of high frequency phenomena He shows how nonlinear effects are reflected in the asymptotic theory In the article Harmonic Analysis Wavelets and Applications by Daubechies and Gilbert the main structure of the wavelet theory is presented Also included are articles on

the more specialized courses that were presented such as Nonlinear Schr dinger Equations by Jean Bourgain and Waves and Transport by George Papanicolaou and Leonid Ryzhik Susan Friedlander provides a written version of her lecture series Stability and Instability of an Ideal Fluid given at the Mentoring Program for Women in Mathematics a preliminary program to the Summer Session This Summer Session brought together students fellows and established mathematicians from all over the globe to share ideas in a vibrant and exciting atmosphere This book presents the compelling results Members of the Mathematical Association of America MAA and the National Council of Teachers of Mathematics NCTM receive a 20% discount from list price **Hyperbolic Partial Differential Equations and Geometric Optics** Jeffrey Rauch,2012-05-01 This book introduces graduate students and researchers in mathematics and the sciences to the multifaceted subject of the equations of hyperbolic type which are used in particular to describe propagation of waves at finite speed Among the topics carefully presented in the book are nonlinear geometric optics the asymptotic analysis of short wavelength solutions and nonlinear interaction of such waves Studied in detail are the damping of waves resonance dispersive decay and solutions to the compressible Euler equations with dense oscillations created by resonant interactions Many fundamental results are presented for the first time in a textbook format In addition to dense oscillations these include the treatment of precise speed of propagation and the existence and stability questions for the three wave interaction equations One of the strengths of this book is its careful motivation of ideas and proofs showing how they evolve from related simpler cases This makes the book quite useful to both researchers and graduate students interested in hyperbolic partial differential equations Numerous exercises encourage active participation of the reader The author is a professor of mathematics at the University of Michigan A recognized expert in partial differential equations he has made important contributions to the transformation of three areas of hyperbolic partial differential equations nonlinear microlocal analysis the control of waves and nonlinear geometric optics

Partial Differential Equations III Michael Taylor,2013-11-11 Partial differential equations is a many faceted subject Created to describe the mechanical behavior of objects such as vibrating strings and blowing winds it has developed into a body of material that interacts with many branches of math ematics such as differential geometry complex analysis and harmonic analysis as weIl as a ubiquitous factor in the description and elucidati n of problems in mathematical physics This work is intended to provide a course of study of some of the major aspects ofPDE 1t is addressed to readers with a background in the basic introductory grad uate mathematics courses in American universities elementary real and complex analysis differential geometry and measure theory Chapter 1 provides background material on the theory of ordinary differential equations ODE This includes both very basic material on topics such as the existence and uniqueness of solutions to ODE and explicit solutions to equations with constant coefficients and relations to linear algebra and more sophisticated resuIts on ftows generated by vector fields connections with differential geom etry the calculus of differential forms stationary action principles in mechanics and their relation to Hamiltonian systems We discuss equations of relativistic

motion as weIl as equations of classical Newtonian mechanics There are also applications to topological resuIts such as degree theory the Brouwer fixed point theorem and the Jordan Brouwer separation theorem In this chapter we also treat scalar first order PDE via Hamilton Jacobi theory Proceedings of the Third Asian Mathematical Conference 2000 Toshikazu Sunada,Polly Wee Sy,2002 COntains 55 research and expository articles on a wide range of currently active and interesting areas in pure and applied mathematics Pseudodifferential Operators and Nonlinear PDE Michael Taylor,2012-12-06 For the past 25 years the theory of pseudodifferential operators has played an important role in many exciting and deep investigations into linear PDE Over the past decade this tool has also begun to yield interesting results in nonlinear PDE This book is devoted to a summary and reconsideration of some used of pseudodifferential operator techniques in nonlinear PDE One goal has been to build a bridge between two approaches which have been used in a number of papers written in the last decade one being the theory of paradifferential operators pioneered by Bony and Meyer the other the study of pseudodifferential operators whose symbols have limited regularity The latter approach is a natural successor to classical devices of deriving estimates for linear PDE whose coefficients have limited regularity in order to obtain results in nonlinear PDE After developing the requisite tools we proceed to demonstrate their effectiveness on a range of basic topics in nonlinear PDE For example for hyperbolic systems known sufficient conditions for persistence of solutions are both sharpened and extended in scope In the treatment of parabolic equations and elliptic boundary problems it is shown that the results obtained here interface particularly easily with the DeGiorgi Nash Moser theory when that theory applies To make the work reasonable self contained there are appendices treating background topics in harmonic analysis and the DeGiorgi Nash Moser theory as well as an introductory chapter on pseudodifferential operators as developed for linear PDE The book should be of interest to graduate students instructors and researchers interested in partial differential equations nonlinear analysis in classical mathematical physics and differential geometry and in harmonic analysis Nonlinear Wave Equations Satyanad Kichenassamy,2021-05-30 This work examines the mathematical aspects of nonlinear wave propagation emphasizing nonlinear hyperbolic problems It introduces the tools that are most effective for exploring the problems of local and global existence singularity formation and large time behaviour of solutions and for the study of perturbation methods

Partial Differential Equations III Michael E. Taylor,2023-12-06 The third of three volumes on partial differential equations this is devoted to nonlinear PDE It treats a number of equations of classical continuum mechanics including relativistic versions as well as various equations arising in differential geometry such as in the study of minimal surfaces isometric imbedding conformal deformation harmonic maps and prescribed Gauss curvature In addition some nonlinear diffusion problems are studied It also introduces such analytical tools as the theory of L p Sobolev spaces Holder spaces Hardy spaces and Morrey spaces and also a development of Calderon Zygmund theory and paradifferential operator calculus The book is targeted at graduate students in mathematics and at professional mathematicians with an interest in partial

differential equations mathematical physics differential geometry harmonic analysis and complex analysis The third edition further expands the material by incorporating new theorems and applications throughout the book and by deepening connections and relating concepts across chapters It includes new sections on rigid body motion on probabilistic results related to random walks on aspects of operator theory related to quantum mechanics on overdetermined systems and on the Euler equation for incompressible fluids The appendices have also been updated with additional results ranging from weak convergence of measures to the curvature of Kahler manifolds Michael E Taylor is a Professor of Mathematics at the University of North Carolina Chapel Hill NC Review of first edition These volumes will be read by several generations of readers eager to learn the modern theory of partial differential equations of mathematical physics and the analysis in which this theory is rooted Peter Lax SIAM review June 1998 **New Trends in the Theory of Hyperbolic Equations** Michael Reissig,Bert-Wolfgang Schulze,2006-03-21 Presenting several developments in the theory of hyperbolic equations this book s contributions deal with questions of low regularity critical growth ill posedness decay estimates for solutions of different non linear hyperbolic models and introduce new approaches based on microlocal methods **Partial Differential Equations and Mathematical Physics** Kunihiko Kajitani,Jean Vaillant,2012-12-06 The 17 invited research articles in this volume all written by leading experts in their respective fields are dedicated to the great French mathematician Jean Leray A wide range of topics with significant new results detailed proofs are presented in the areas of partial differential equations complex analysis and mathematical physics Key subjects are Treated from the mathematical physics viewpoint nonlinear stability of an expanding universe the compressible Euler equation spin groups and the Leray Maslov index Linked to the Cauchy problem an intermediate case between effective hyperbolicity and the Levi condition global Cauchy Kowalewski theorem in some Gevrey classes the analytic continuation of the solution necessary conditions for hyperbolic systems well posedness in the Gevrey class uniformly diagonalizable systems and reduced dimension and monodromy of ramified Cauchy problem Additional articles examine results on Local solvability for a system of partial differential operators The hypoellipticity of second order operators Differential forms and Hodge theory on analytic spaces Subelliptic operators and sub Riemannian geometry Contributors V Ancona R Beals A Bove R Camales Y Choquet Bruhat F Colombini M De Gosson S De Gosson M Di Flaviano B Gaveau D Gourdin P Greiner Y Hamada K Kajitani M Mechab K Mizohata V Moncrief N Nakazawa T Nishitani Y Ohya T Okaji S Ouchi S Spagnolo J Vaillant C Wagschal S Wakabayashi The book is suitable as a reference text for graduate students and active researchers Analytic Semigroups and Optimal Regularity in Parabolic Problems Alessandra Lunardi,1995-01-27 The book shows how the abstract methods of analytic semigroups and evolution equations in Banach spaces can be fruitfully applied to the study of parabolic problems Particular attention is paid to optimal regularity results in linear equations Furthermore these results are used to study several other problems especially fully nonlinear ones Owing to the new unified approach chosen known theorems are presented from a novel perspective and new results are

derived The book is self contained It is addressed to PhD students and researchers interested in abstract evolution equations and in parabolic partial differential equations and systems It gives a comprehensive overview on the present state of the art in the field teaching at the same time how to exploit its basic techniques This very interesting book provides a systematic treatment of the basic theory of analytic semigroups and abstract parabolic equations in general Banach spaces and how this theory may be used in the study of parabolic partial differential equations it takes into account the developments of the theory during the last fifteen years For instance optimal regularity results are a typical feature of abstract parabolic equations they are comprehensively studied in this book and yield new and old regularity results for parabolic partial differential equations and systems Mathematical Reviews Motivated by applications to fully nonlinear problems the approach is focused on classical solutions with continuous or H lder continuous derivatives Zentralblatt MATH **Variational Methods for Discontinuous Structures** Raul Serapioni,Franco Tomarelli,2012-12-06 In recent years many researchers in material science have focused their attention on the study of composite materials equilibrium of crystals and crack distribution in continua subject to loads At the same time several new issues in computer vision and image processing have been studied in depth The understanding of many of these problems has made significant progress thanks to new methods developed in calculus of variations geometric measure theory and partial differential equations In particular new technical tools have been introduced and successfully applied For example in order to describe the geometrical complexity of unknown patterns a new class of problems in calculus of variations has been introduced together with a suitable functional setting the free discontinuity problems and the special BV and BH functions The conference held at Villa Olmo on Lake Como in September 1994 spawned successful discussion of these topics among mathematicians experts in computer science and material scientists **Flow Lines and Algebraic Invariants in Contact Form Geometry** Abbas Bahri,2012-12-06 This text features a careful treatment of flow lines and algebraic invariants in contact form geometry a vast area of research connected to symplectic field theory pseudo holomorphic curves and Gromov Witten invariants contact homology In particular this work develops a novel algebraic tool in this field rooted in the concept of critical points at infinity the new algebraic invariants defined here are useful in the investigation of contact structures and Reeb vector fields The book opens with a review of prior results and then proceeds through an examination of variational problems non Fredholm behavior true and false critical points at infinity and topological implications An increasing convergence with regular and singular Yamabe type problems is discussed and the intersection between contact form and Riemannian geometry is emphasized with a specific focus on a unified approach to non compactness in both disciplines Fully detailed explicit proofs and a number of suggestions for further research are provided throughout Rich in open problems and written with a global view of several branches of mathematics this text lays the foundation for new avenues of study in contact form geometry Graduate students and researchers in geometry partial differential equations and related fields will benefit from the book s breadth and unique

perspective *Periodic Solutions of Singular Lagrangian Systems* A. Ambrosetti,V. Coti-Zelati,2012-12-06 Thismonographdealswiththeexistenceofperiodicmotionsof Lagrangiansystemswith ndegreesoffreedom ij V q 0 where Visasingularpotential Aprototypeofsuchaproblem evenifitisnottheonlyphysicallyinterestingone istheKepler problem q 0 q yqr This jointlywiththemoregeneralN bodyproblem hasalways beentheobjectofagreatdealofresearch Mostofthoseresults arebasedonperturbationmethods andmakeuseofthespecific featuresoftheKeplerpotential OurapproachismoreonthelinesofNonlinearFunctional Analysis ourmainpurposeistogiveafunctionalframefor systemswithsingularpotentials includingtheKeplerandthe N bodyproblemasparticularcases PreciselyweuseCritical PointTheorytoobtainexistenceresults qualitativeinnature whichholdtrueforbroadclassesofpotentials Thishighlights thatthevariationalmethods whichhavebeenemployedtoob tainimportantadvancesinthestudyofregularHamiltonian systems canbesuccessfallyusedtohandlesingularpotentials aswell Theresearchonthistopicisstillinevolution andtherefore theresultswewillpresentarenottobeintendedasthefinal ones Indeedamajorpurposeofourdiscussionistopresent methodsandtoolswhichhavebeenusedinstudyingsuchprob lems Vlll PREFACE Partofthematerialofthisvolumehasbeenpresentedina seriesoflecturesgivenbytheauthorsatSISSA Trieste whom wewouldliketothankfortheirhospitalityandsupport We wishalsotothankUgoBessi PaoloCaldiroli FabioGiannoni LouisJeanjean LorenzoPisani EnricoSerra KazunakaTanaka EnzoVitillaroforhelpfulsuggestions May26 1993 Notation n 1 For x yE IR x ydenotestheEuclideanScalarproduct and IxltheEuclideannorm 2 meas A denotestheLebesguemeasureofthesubset Aof n IR 3 Wedenoteby ST 0 T a T theunitarycirclepara metrizedby t E 0 T Wewillalsowrite SI ST I n 1 n 4 Wewillwrite sn xE IR Ixl I andn IR O n 5 Wedenoteby LP O T IR 1 p 00 theLebesgue spaces equippedwiththestandardnorm lIulip l n l n 6 H ST IR denotestheSobolevspaceof u E H 2 0 T IR suchthat u O u T Thenormin HIwillbedenoted by lIull2 lIull lIull 7 Wedenoteby 1 and11 11respectivelythescalarproduct andthenormoftheHilbertspace E 8 For uE E EHilbertorBanachspace wedenotetheball ofcenter uandradiusrby B u r vE E lIu vii r Wewillalsowrite B B O r r 1 1 9 WesetA n uE H St n k 10 For VE C 1Rxil IR wedenoteby V t x thegradient of Vwithrespectto x l 11 Given f E C M IR MHilbertmanifold welet r uEM f u a f l a b uE E a f u b x NOTATION 12 Given f E C1 M JR MHilbertmanifold wewilldenote by Zthesetofcriticalpointsof fon Mandby Zctheset Z U f l c c 13 Givenasequence UnE E EHilbertspace by Un Uwe willmeanthatthesequence Unconvergesweaklyto u 14 With E wewilldenotethesetoflinearandcontinuous operatorson E 15 With Ck A JR wewilldenotethesetoffunctions ffrom AtoJR ktimesdifferentiablewhosek derivativeisHolder continuousofexponent0 Main Assumptions Wecollecthere forthereader sconvenience themainassump tionsonthepotential Vusedthroughoutthebook VO VEC1 lRXO lR V t T x V t X V t x ElRXO VI V t x **Infinite Dimensional Morse Theory and Multiple Solution Problems** K.C. Chang,2012-12-06 The book is based on my lecture notes Infinite dimensional Morse theory and its applications 1985 Montreal and one semester of graduate lectures delivered at the University of Wisconsin Madison 1987 Since the aim of this monograph is to give a unified account of the

topics in critical point theory a considerable amount of new materials has been added Some of them have never been published previously The book is of interest both to researchers following the development of new results and to people seeking an introduction into this theory The main results are designed to be as self contained as possible And for the reader s convenience some preliminary background information has been organized The following people deserve special thanks for their direct roles in help ing to prepare this book Prof L Nirenberg who first introduced me to this field ten years ago when I visited the Courant Institute of Math Sciences Prof A Granas who invited me to give a series of lectures at SMS 1983 Montreal and then the above notes as the primary version of a part of the manuscript which were published in the SMS collection Prof P Rabinowitz who provided much needed encouragement during the academic semester and invited me to teach a semester graduate course after which the lecture notes became the second version of parts of this book Professors A Bahri and H Brezis who suggested the publication of the book in the Birkhiiuser series **The Monge—Ampère Equation** Cristian E. Gutierrez,2012-12-06 In recent years the study of the Monge Ampere equation has received consider able attention and there have been many important advances As a consequence there is nowadays much interest in this equation and its applications This volume tries to reflect these advances in an essentially self contained systematic exposi tion of the theory of weak solutions including recent regularity results by L A Caffarelli The theory has a geometric flavor and uses some techniques from har monic analysis such us covering lemmas and set decompositions An overview of the contents of the book is as follows We shall be concerned with the Monge Ampere equation which for a smooth function u is given by 0 0 1 There is a notion of generalized or weak solution to 0 0 1 for u convex in a domain n one can define a measure Mu in n such that if u is smooth then Mu 2 has density det D u Therefore u is a generalized solution of 0 0 1 if M u f **Differential Inclusions in Nonsmooth Mechanical Problems** Monteiro Marques,2013-11-11 The book is devoted to evolution problems which arise in the dynamics of mechanical systems involving unilateral constraints possibly in the presence of dry friction Collisions may be the result In such a context the velocity function cannot be expected to be absolutely continuous so the traditional theory of differential equations or inclusions does not apply Some effective numerical techniques have been proposed but existence results were missing until now This book starts filling that gap At first some typical mathematical tools are introduced such as compactness results in the space of vector functions of bounded variation in time and approximation in the sense of graphs The sweeping process by a moving convex set in a Hilbert space plays a central role The latest existence results concerning this process are presented in chapter 2 In chapters 3 and 4 the study of the mechanical problems is undertaken Connected areas of research are briefly reviewed in chapter 5 Proofs are constructive whenever possible and convergence of algorithms is often considered The book presupposes only a moderate background in functional analysis **Variational Methods in Image Segmentation** Jean-Michel Morel,Sergio Solimini,2012-12-06 This book contains both a synthesis and mathematical analysis of a wide set of algorithms and theories whose aim is the automatic segmen tation of digital images as

well as the understanding of visual perception A common formalism for these theories and algorithms is obtained in a variational form Thank to this formalization mathematical questions about the soundness of algorithms can be raised and answered Perception theory has to deal with the complex interaction between regions and edges or boundaries in an image in the variational seg mentation energies edge terms compete with region terms in a way which is supposed to impose regularity on both regions and boundaries This fact was an experimental guess in perception phenomenology and computer vision until it was proposed as a mathematical conjecture by Mumford and Shah The third part of the book presents a unified presentation of the evi dences in favour of the conjecture It is proved that the competition of one dimensional and two dimensional energy terms in a variational for mulation cannot create fractal like behaviour for the edges The proof of regularity for the edges of a segmentation constantly involves con cepts from geometric measure theory which proves to be central in im age processing theory The second part of the book provides a fast and self contained presentation of the classical theory of rectifiable sets the edges and unrectifiable sets fractals

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