

Geometric approach for differential equations

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Abstract

Present differential equations solver are often based on a list of equations the solutions of which one knows (e.g. as listed in [9]). Each equation of this list and its solution are ordered in a table. Significant progress would be made if it was possible to compute in advance the differential invariants that allow to decide if one equation to solve is equivalent to one of the list by a change of coordinates. We will show that, for the computation of these invariants, a geometrical approach offers advantages over non geometrical approaches (e.g. such as that of Riquier, Ritt, Kolchin etc.)

The sought change of coordinates is solution of certain PDE system. Differential algebra allows to compute the integrability conditions of this PDE system. Although, in practice one is often confronted with computer output consisting of several pages of intricate formulae. Even so, for more complicated equivalence problems with higher complexity such those coming from biology, physics, etc. differential algebra is not efficient due to expression swell.

In his equivalence method, E. Cartan [5] formulated the PDE system in term of linear Pfaffian system. Then the required conditions are computed with a process called absorption of torsion leading to sparse structure equations. In addition, this computation is done by separately and symmetrically treating the linear Pfaffian system and this has the effect of dividing the number of variables by two. Cartan's method has a wide range of applications to problems arising in classical invariant theory, differential equation classification, exact solution of PDEs, general relativity and many others.

Cartan's equivalence method is complementary to Lie symmetry method. In the case when the equation which we want to solve admits the symmetry group of finite cardinality, we prove that the sought change of coordinates can be computed without integrating differential equation.

keywords : Cartan's method; differential algebra.

1 Introduction

Two systems of differential equations E_f and $E_{\tilde{f}}$ are said to be equivalent under a pseudo-group of transformations Φ (we write $E_f \sim_{\Phi} E_{\tilde{f}}$) if and only if there exist a local diffeomorphism $\phi \in \Phi$ wich map the solutions of $E_{\tilde{f}}$ to the solutions of E_f . The change of coordinates $\phi \in \Phi$ is solution of a PDE system that we can compute by an algorithm. A program like DIFFALG or RIF can compute the integrability conditions of such a PDE system, then the existence of ϕ is decidable.

EXAMPLE Consider two ordinary differential equations (E_f) and $(E_{\tilde{f}})$ of the form

$$\frac{d^2y}{dx^2} = f\left(x, y, \frac{dy}{dx}\right) \quad \text{and} \quad \frac{d^2\tilde{y}}{d\tilde{x}^2} = \tilde{f}\left(\tilde{x}, \tilde{y}, \frac{d\tilde{y}}{d\tilde{x}}\right) \quad (1)$$

and Φ the pseudo-group of local diffeomorphisms $\phi : \mathbb{R}^2 \rightarrow \mathbb{R}^2$ defined by the Lie equations

$$\frac{\partial \tilde{x}}{\partial x} = 1, \quad \frac{\partial \tilde{x}}{\partial y} = 0, \quad \frac{\partial \tilde{y}}{\partial y} \neq 0.$$

Geometric Approaches To Differential Equations

Bernard F. Schutz



Geometric Approaches To Differential Equations:

Geometric Approaches to Differential Equations Peter J. Vassiliou, Ian G. Lisle, 2000-03-13 A concise and accessible introduction to the wide range of topics in geometric approaches to differential equations

Geometric Numerical Integration Ernst Hairer, Christian Lubich, Gerhard Wanner, 2006-05-18 This book covers numerical methods that preserve properties of Hamiltonian systems reversible systems differential equations on manifolds and problems with highly oscillatory solutions It presents a theory of symplectic and symmetric methods which include various specially designed integrators as well as discusses their construction and practical merits The long time behavior of the numerical solutions is studied using a backward error analysis combined with KAM theory

Geometrical Approaches to Differential Equations R. Martini, 2006-11-15

Geometry in Partial Differential Equations Agostino Prastaro, Themistocles M. Rassias, 1994 This book emphasizes the interdisciplinary interaction in problems involving geometry and partial differential equations It provides an attempt to follow certain threads that interconnect various approaches in the geometric applications and influence of partial differential equations A few such approaches include Morse Palais Smale theory in global variational calculus general methods to obtain conservation laws for PDEs structural investigation for the understanding of the meaning of quantum geometry in PDEs extensions to super PDEs formulated in the category of supermanifolds of the geometrical methods just introduced for PDEs and the harmonic theory which proved to be very important especially after the appearance of the Atiyah Singer index theorem which provides a link between geometry and topology

Geometrical Approaches to Differential Equations R. Martini, 2014-01-15

Applications of Analytic and Geometric Methods to Nonlinear Differential Equations P.A. Clarkson, 1993-09-30 In the study of integrable systems two different approaches in particular have attracted considerable attention during the past twenty years 1 The inverse scattering transform IST using complex function theory which has been employed to solve many physically significant equations the soliton equations 2 Twistor theory using differential geometry which has been used to solve the self dual Yang Mills SDYM equations a four dimensional system having important applications in mathematical physics Both soliton and the SDYM equations have rich algebraic structures which have been extensively studied Recently it has been conjectured that in some sense all soliton equations arise as special cases of the SDYM equations subsequently many have been discovered as either exact or asymptotic reductions of the SDYM equations Consequently what seems to be emerging is that a natural physically significant system such as the SDYM equations provides the basis for a unifying framework underlying this class of integrable systems i e soliton systems This book contains several articles on the reduction of the SDYM equations to soliton equations and the relationship between the IST and twistor methods The majority of nonlinear evolution equations are nonintegrable and so asymptotic numerical perturbation and reduction techniques are often used to study such equations This book also contains articles on perturbed soliton equations Painlevé analysis of partial differential equations studies of the Painlevé equations and

symmetry reductions of nonlinear partial differential equations ABSTRACT In the study of integrable systems two different approaches in particular have attracted considerable attention during the past twenty years the inverse scattering transform IST for soliton equations and twistor theory for the self dual Yang Mills SDYM equations This book contains several articles on the reduction of the SDYM equations to soliton equations and the relationship between the IST and twistor methods Additionally it contains articles on perturbed soliton equations Painlevé analysis of partial differential equations studies of the Painlevé equations and symmetry reductions of nonlinear partial differential equations Reduction of Nonlinear Control Systems V.I. Elkin, 2012-12-06 Advances in science and technology necessitate the use of increasingly complicated dynamic control processes Undoubtedly sophisticated mathematical models are also concurrently elaborated for these processes In particular linear dynamic control systems $\dot{y} = Ay + Bu$ where A and B are constants are often abandoned in favor of nonlinear dynamic control systems which in addition contain a large number of equations The solution of problems for multidimensional nonlinear control systems encounters serious difficulties which are both mathematical and technical in nature Therefore it is imperative to develop methods of reduction of nonlinear systems to a simpler form for example decomposition into systems of lesser dimension Approaches to reduction are diverse in particular techniques based on approximation methods In this monograph we elaborate the most natural and obvious in our opinion approach which is essentially inherent in any theory of mathematical entities for instance in the theory of linear spaces theory of groups etc Reduction in our interpretation is based on assigning to the initial object an isomorphic object a quotient object and a subobject In the theory of linear spaces for instance reduction consists in reducing to an isomorphic linear space quotient space and subspace Strictly speaking the exposition of any mathematical theory essentially begins with the introduction of these reduced objects and determination of their basic properties in relation to the initial object *Differential Geometric Methods in Theoretical Physics* Ling-Lie Chau, Werner Nahm, 2013-06-29 After several decades of reduced contact the interaction between physicists and mathematicians in the front line research of both fields recently became deep and fruitful again Many of the leading specialists of both fields became involved in this development This process even led to the discovery of previously unsuspected connections between various subfields of physics and mathematics In mathematics this concerns in particular knots von Neumann algebras Kac-Moody algebras integrable nonlinear partial differential equations and differential geometry in low dimensions most importantly in three and four dimensional spaces In physics it concerns gravity string theory integrable classical and quantum field theories solitons and the statistical mechanics of surfaces New discoveries in these fields are made at a rapid pace This conference brought together active researchers in these areas reporting their results and discussing with other participants to further develop thoughts in future new directions The conference was attended by 50 participants from 15 nations These proceedings document the program and the talks at the conference This conference was preceded by a two week summer school Ten lecturers gave extended lectures on related

topics The proceedings of the school will also be published in the NATO AS volume by Plenum The Editors vii

ACKNOWLEDGMENTS We would like to thank the many people who have made the conference a success Furthermore we appreciate the excellent talks The active participation of everyone present made the conference lively and stimulating All of this made our efforts worth while Differential Geometric Methods in the Control of Partial Differential Equations Robert Gulliver,2000 This volume contains selected papers that were presented at the AMS IMS SIAM Joint Summer Research Conference on Differential Geometric Methods in the Control of Partial Differential Equations which was held at the University of Colorado in Boulder in June 1999 The aim of the conference was to explore the infusion of differential geometric methods into the analysis of control theory of partial differential equations particularly in the challenging case of variable coefficients where the physical characteristics of the medium vary from point to point While a mutually profitable link has been long established for at least 30 years between differential geometry and control of ordinary differential equations a comparable relationship between differential geometry and control of partial differential equations PDEs is a new and promising topic Very recent research just prior to the Colorado conference supported the expectation that differential geometric methods when brought to bear on classes of PDE modelling and control problems with variable coefficients will yield significant mathematical advances The papers included in this volume written by specialists in PDEs and control of PDEs as well as by geometers collectively support the claim that the aims of the conference are being fulfilled In particular they endorse the belief that both subjects differential geometry and control of PDEs have much to gain by closer interaction with one another Consequently further research activities in this area are bound to grow *Geometric Methods and Applications* Jean Gallier,2012-12-06 As an introduction to fundamental geometric concepts and tools needed for solving problems of a geometric nature using a computer this book attempts to fill the gap between standard geometry books which are primarily theoretical and applied books on computer graphics computer vision or robotics which sometimes do not cover the underlying geometric concepts in detail Gallier offers an introduction to affine geometry projective geometry Euclidean geometry basics of differential geometry and Lie groups and a glimpse of computational geometry convex sets Voronoi diagrams and Delaunay triangulations and explores many of the practical applications of geometry Some of these applications include computer vision camera calibration efficient communication error correcting codes cryptography motion interpolation and robot kinematics This comprehensive text covers most of the geometric background needed for conducting research in computer graphics geometric modeling computer vision and robotics and as such will be of interest to a wide audience including computer scientists mathematicians and engineers A Computational Differential Geometry Approach to Grid Generation Vladimir D. Liseikin,2013-03-14 Grid technology whose achievements have significant impact on the efficiency of numerical codes still remains a rapidly advancing field of computational and applied mathematics New achievements are being added by the creation of more sophisticated techniques modification of the available methods and

implementation of more subtle tools as well as the results of the theories of differential equations calculus of variations and Riemannian geometry being applied to the formulation of grid models and analysis of grid properties The development of comprehensive differential and variational grid generation techniques reviewed in the monographs of J F Thompson Z U A Warsi C W Mastin P Knupp S Steinberg V D Liseikin has been largely based on a popular concept in accordance with which a grid model realizing the required grid properties should be formulated through a linear combination of basic and control grid operators with weights A typical basic grid operator is the operator responsible for the well posedness of the grid model and construction of unfolding grids e g the Laplace equations generalized Laplace equations for surfaces or the functional of grid smoothness which produces fixed nonfolding grids while grid clustering is controlled by source terms in differential grid formulations or by an adaptation functional in variational models However such a formulation does not obey the fundamental invariance laws with respect to parameterizations of physical geometries It frequently results in cumbersome governing grid equations whose choice of weight and control functions provide conflicting grid requirements Geometrical Methods in the Theory of Ordinary Differential Equations V.I. Arnold, 2012-12-06 Since the first edition of this book geometrical methods in the theory of ordinary differential equations have become very popular and some progress has been made partly with the help of computers Much of this progress is represented in this revised expanded edition including such topics as the Feigenbaum universality of period doubling the Zoladec solution the Iljashenko proof the Ecalle and Voronin theory the Varchenko and Hovanski theorems and the Neistadt theory In the selection of material for this book the author explains basic ideas and methods applicable to the study of differential equations Special efforts were made to keep the basic ideas free from excessive technicalities Thus the most fundamental questions are considered in great detail while of the more special and difficult parts of the theory have the character of a survey Consequently the reader needs only a general mathematical knowledge to easily follow this text It is directed to mathematicians as well as all users of the theory of differential equations

Differential Equations - Geometry, Symmetries and Integrability Boris Kruglikov, Valentin Lychagin, Eldar Straume, 2009-07-24 The Abel Symposium 2008 focused on the modern theory of differential equations and their applications in geometry mechanics and mathematical physics Following the tradition of Monge Abel and Lie the scientific program emphasized the role of algebro geometric methods which nowadays permeate all mathematical models in natural and engineering sciences The ideas of invariance and symmetry are of fundamental importance in the geometric approach to differential equations with a serious impact coming from the area of integrable systems and field theories This volume consists of original contributions and broad overview lectures of the participants of the Symposium The papers in this volume present the modern approach to this classical subject **Geometric Methods in Mathematical Physics** G. Kaiser, J.E. Marsden, 2006-11-14 For too many students mathematics consists of facts in a vacuum to be memorized because the instructor says so and to be forgotten when the course of study is completed In this all too common scenario young learners

often miss the chance to develop skills specifically reasoning skills that can serve them for a lifetime The elegant pages of Teaching Mathematical Reasoning in Secondary School Classrooms propose a more positive solution by presenting a reasoning and discussion based approach to teaching mathematics emphasizing the connections between ideas or why math works The teachers whose work forms the basis of the book create a powerful record of methods interactions and decisions including dealing with challenges and impasses involving this elusive topic And because this approach shifts the locus of authority from the instructor to mathematics itself students gain a system of knowledge that they can apply not only to discrete tasks relating to numbers but also to the larger world of people and the humanities A sampling of the topics covered Whole class discussion methods for teaching mathematics reasoning Learning mathematical reasoning through tasks Teaching mathematics using the five strands Classroom strategies for promoting mathematical reasoning Maximizing student contributions in the classroom Overcoming student resistance to mathematical conversations Teaching Mathematical Reasoning in Secondary School Classrooms makes a wealth of cutting edge strategies available to mathematics teachers and teacher educators This book is an invaluable resource for researchers in mathematics and curriculum reform and of great interest to teacher educators and teachers

Geometric Methods in Inverse Problems and PDE Control Chrisopher B. Croke, Gunther Uhlmann, Irena Lasiecka, Michael Vogelius, 2012-12-06 This IMA Volume in Mathematics and its Applications GEOMETRIC METHODS IN INVERSE PROBLEMS AND PDE CONTROL contains a selection of articles presented at 2001 IMA Summer Program with the same title We would like to thank Christopher B Croke University of Penn sylva nia Irena Lasiecka University of Virginia Gunther Uhlmann University of Washington and Michael S Vogelius Rutgers University for their ex cellent work as organizers of the two week summer workshop and for editing the volume We also take this opportunity to thank the National Science Founda tion for their support of the IMA Series Editors Douglas N Arnold Director of the IMA Fadil Santosa Deputy Director of the IMA v PREFACE This volume contains a selected number of articles based on lectures delivered at the IMA 2001 Summer Program on Geometric Methods in Inverse Problems and PDE Control The focus of this program was some common techniques used in the study of inverse coefficient problems and control problems for partial differential equations with particular emphasis on their strong relation to fundamental problems of geometry Inverse coef ficient problems for partial differential equations arise in many application areas for instance in medical imaging nondestructive testing and geophys ical prospecting Control problems involving partial differential equations may arise from the need to optimize a given performance criterion e g to dampen out undesirable vibrations of a structure or more generally to obtain a prescribed behaviour of the dynamics

Geometric Methods in Inverse Problems and PDE Control Chrisopher B. Croke, 2004-02-26 This volume contains a selection of articles based on lectures delivered at the IMA 2001 Summer Program on Geometric Methods in Inverse Problems and PDE Control The articles are focused around a set of common tools used in the study of inverse coefficient and control problems for PDEs and related differential geometric

problems This book will serve as an excellent starting point for researchers wanting to pursue studies at the intersection of these mathematically exciting and practically important subjects *Topics in the Geometric Theory of Linear Systems*
 Robert Hermann,1984 **Differential Equations** Solomon Lefschetz,1957 *A New Approach to Differential Geometry using Clifford's Geometric Algebra* John Snygg,2011-12-09 Differential geometry is the study of the curvature and calculus of curves and surfaces A New Approach to Differential Geometry using Clifford s Geometric Algebra simplifies the discussion to an accessible level of differential geometry by introducing Clifford algebra This presentation is relevant because Clifford algebra is an effective tool for dealing with the rotations intrinsic to the study of curved space Complete with chapter by chapter exercises an overview of general relativity and brief biographies of historical figures this comprehensive textbook presents a valuable introduction to differential geometry It will serve as a useful resource for upper level undergraduates beginning level graduate students and researchers in the algebra and physics communities **Geometrical Methods of Mathematical Physics** Bernard F. Schutz,1980-01-28 For physicists and applied mathematicians working in the fields of relativity and cosmology high energy physics and field theory thermodynamics fluid dynamics and mechanics This book provides an introduction to the concepts and techniques of modern differential theory particularly Lie groups Lie forms and differential forms

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