Computing Singularly Perturbed Differential Equations

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June 30, 2017

Abstract

A computational tool for coarse-graining nonlinear systems of ordinary differential equations in time is discussed. Three illustrative model examples are worked out that demonstrate the range of capability of the method. This includes the averaging of Hamiltonian as well as dissipative microscopic dynamics whose 'slow' variables, defined in a precise sense, can often display mixed slow-fast response as in relaxation oscillations, and dependence on initial conditions of the fast variables. Also covered is the case where the quasi-static assumption in solid mechanics is violated. The computational tool is demonstrated to capture all of these behaviors in an accurate and robust manner, with significant savings in time. A practically useful strategy for initializing short bursts of microscopic runs for the accurate computation of the evolution of slow variables is also developed.

1 Introduction

This paper is concerned with a computational tool for understanding the behavior of systems of evolution, governed by (nonlinear) ordinary differential equations, on a time scale that is much slower than the time scales of the intrinsic dynamics. A paradigmatic example is a molecular dynamic assembly under loads, where the characteristic time of the applied loading is very much larger than the period of atomic vibrations. We examine appropriate theory for such applications and devise a computational algorithm. The singular perturbation problems we address contain a small parameter ϵ that reflects the ratio between the slow and the fast time scales. In many cases, the solutions of the problem obtained by setting the small parameter to zero matches solutions to the full problem with small ϵ, except in a small region - a boundary/initial layer. But, there are situations, where the limit of solutions of the original problem as ϵ tends to zero does not match the solution of the problem obtained by setting the small parameter to zero. Our paper covers this aspect as well. In the next section we present the framework of the present study, and its sources. Before displaying our algorithm

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Numerical Methods for Singularly Perturbed Differential Equations Hans-Görg Roos,Martin Stynes,Lutz Tobiska,2013-06-29 The analysis of singular perturbed differential equations began early in this century when approximate solutions were constructed from asymptotic ex pansions Preliminary attempts appear in the nineteenth century vD94 This technique has flourished since the mid 1960s Its principal ideas and methods are described in several textbooks Nevertheless asymptotic ex pansions may be impossible to construct or may fail to simplify the given problem then numerical approximations are often the only option The systematic study of numerical methods for singular perturbation problems started somewhat later in the 1970s While the research frontier has been steadily pushed back the exposition of new developments in the analysis of numerical methods has been neglected Perhaps the only example of a textbook that concentrates on this analysis is DMS80 which collects various results for ordinary differential equations but many methods and techniques that are relevant today especially for partial differential equa tions were developed after 1980 Thus contemporary researchers must comb the literature to acquaint themselves with earlier work Our purposes in writing this introductory book are twofold First we aim to present a structured account of recent ideas in the numerical analysis of singularly perturbed differential equations Second this important area has many open problems and we hope that our book will stimulate further investigations Our choice of topics is inevitably personal and reflects our own main interests   Fitted Numerical Methods For Singular Perturbation Problems: Error Estimates In The Maximum Norm For Linear Problems In One And Two Dimensions (Revised Edition) John J H Miller,Eugene O'riordan,G I Shishkin,2012-02-29 Since the first edition of this book the literature on fitted mesh methods for singularly perturbed problems has expanded significantly Over the intervening years fitted meshes have been shown to be effective for an extensive set of singularly perturbed partial differential equations In the revised version of this book the reader will find an introduction to the basic theory associated with fitted numerical methods for singularly perturbed differential equations Fitted mesh methods focus on the appropriate distribution of the mesh points for singularly perturbed problems The global errors in the numerical approximations are measured in the pointwise maximum norm The fitted mesh algorithm is particularly simple to implement in practice but the theory of why these numerical methods work is far from simple This book can be used as an introductory text to the theory underpinning fitted mesh methods   Singular Perturbation Methods for Ordinary Differential Equations Robert E., Jr. O'Malley,2012-12-06 This book results from various lectures given in recent years Early drafts were used for several single semester courses on singular perturbation meth ods given at Rensselaer and a more complete version was used for a one year course at the Technische Universitat Wien Some portions have been used for short lecture series at Universidad Central de Venezuela West Vir ginia University the University of Southern California the University of California at Davis East China Normal University the University of Texas at Arlington Universita di Padova and the University of New Hampshire among

other places As a result I ve obtained lots of valuable feedback from students and listeners for which I am grateful This writing continues a pattern Earlier lectures at Bell Laboratories at the University of Edin burgh and New York University and at the Australian National University led to my earlier works 1968 1974 and 1978 All seem to have been useful for the study of singular perturbations and I hope the same will be true of this monograph I ve personally learned much from reading and analyzing the works of others so I would especially encourage readers to treat this book as an introduction to a diverse and exciting literature The topic coverage selected is personal and reflects my current opin ions An attempt has been made to encourage a consistent method of ap proaching problems largely through correcting outer limits in regions of rapid change Formal proofs of correctness are not emphasized **Singularly Perturbed Differential Equations** Herbert Goering,Andreas Felgenhauer,Gert Lube,Hans-Görg Roos,Lutz Tobiska,1984-01-14 No detailed description available for Singularly Perturbed Differential Equations **The Theory of Singular Perturbations** E.M. de Jager,J.F. Furu,1996-11-08 The subject of this textbook is the mathematical theory of singular perturbations which despite its respectable history is still in a state of vigorous development Singular perturbations of cumulative and of boundary layer type are presented Attention has been given to composite expansions of solutions of initial and boundary value problems for ordinary and partial differential equations linear as well as quasilinear also turning points are discussed The main emphasis lies on several methods of approximation for solutions of singularly perturbed differential equations and on the mathematical justification of these methods The latter implies a priori estimates of solutions of differential equations this involves the application of Gronwall s lemma maximum principles energy integrals fixed point theorems and G ding s theorem for general elliptic equations These features make the book of value to mathematicians and researchers in the engineering sciences interested in the mathematical justification of formal approximations of solutions of practical perturbation problems The text is selfcontained and each chapter is concluded with some exercises **Singular Perturbations and Hysteresis** Michael P. Mortell,Robert E. O'Malley,Alexei Pokrovskii,Vladimir Sobolev,2005-06-01 This book unifies many important recent developments in the analysis of singular perturbation and hysteresis phenomena in an accessible and comprehensive fashion In April 2002 at University College Cork in Ireland the editors conducted a workshop to provide a forum for experts to share their interests and knowledge For this book the editors have compiled research from those practitioners in areas such as reacting systems semiconductor lasers shock phenomena in economic modeling and fluid mechanics all with an emphasis on hysteresis and singular perturbations A basic introduction to hysteresis and singular perturbation theory is included with simple examples from both physics and mathematics Later chapters address applications of hysteresis to economics various aspects of the asymptotic theory of singularly perturbed systems typical problems of the asymptotic theory of contrast structures and the geometrical approach to an investigation of models with singular perturbations and hysteresis *Robust Numerical Methods for Singularly Perturbed Differential Equations* Hans-Görg Roos,Martin Stynes,Lutz Tobiska,2008-09-17 This new

edition incorporates new developments in numerical methods for singularly perturbed differential equations focusing on linear convection diffusion equations and on nonlinear flow problems that appear in computational fluid dynamics

   Singularly Perturbed Differential Equations Herbert Goering,1983   <u>Algebraic Analysis of Singular Perturbation Theory</u> Takahiro Kawai,Yoshitsugu Takei,2005 The topic of this book is the study of singular perturbations of ordinary differential equations i e perturbations that represent solutions as asymptotic series rather than as analytic functions in a perturbation parameter The main method used is the so called WKB Wentzel Kramers Brillouin method originally invented for the study of quantum mechanical systems The authors describe in detail the WKB method and its applications to the study of monodromy problems for Fuchsian differential equations and to the analysis of Painleve functions This volume is suitable for graduate students and researchers interested in differential equations and special functions   <u>Introduction to the General Theory of Singular Perturbations</u> S. A. Lomov, This book is aimed at researchers and students in physics mathematics and engineering It contains the first systematic presentation of a general approach to the integration of singularly perturbed differential equations describing nonuniform transitions such as the occurrence of a boundary layer discontinuities boundary effects and so on The method of regularization of singular perturbations presented here can be applied to the asymptotic integration of systems of ordinary and partial differential equations   *Singularly Perturbed Boundary-Value Problems* Luminita Barbu,Gheorghe Morosanu,2007-12-14 This book offers a detailed asymptotic analysis of some important classes of singularly perturbed boundary value problems which are mathematical models for phenomena in biology chemistry and engineering The authors are particularly interested in nonlinear problems which have gone little examined so far in literature dedicated to singular perturbations The treatment presented here combines successful results from functional analysis singular perturbation theory partial differential equations and evolution equations   *The Boundary Function Method for Singular Perturbed Problems* Adelaida B. Vasil'eva,Valentin F. Butuzov,Leonid V. Kalachev,1995-01-01 This book is devoted solely to the boundary function method which is one of the asymptotic methods   *Robust Numerical Methods for Singularly Perturbed Differential Equations* Hans-G. Roos,Martin Stynes,Lutz Tobiska,2009-08-29 This new edition incorporates new developments in numerical methods for singularly perturbed differential equations focusing on linear convection diffusion equations and on nonlinear flow problems that appear in computational fluid dynamics   **Numerical Methods for Singularly Perturbed Differential Equations** Hans-Görg Roos,Martin Stynes,Lutz Tobiska,2014-01-15   **Two-Scale Approach to Oscillatory Singularly Perturbed Transport Equations** Emmanuel Frénod,2017-10-05 This book presents the classical results of the two scale convergence theory and explains using several figures why it works It then shows how to use this theory to homogenize ordinary differential equations with oscillating coefficients as well as oscillatory singularly perturbed ordinary differential equations In addition it explores the homogenization of hyperbolic partial differential equations with oscillating coefficients and linear oscillatory singularly perturbed hyperbolic partial differential equations

Further it introduces readers to the two scale numerical methods that can be built from the previous approaches to solve oscillatory singularly perturbed transport equations ODE and hyperbolic PDE and demonstrates how they can be used efficiently This book appeals to master s and PhD students interested in homogenization and numerics as well as to the Iter community   Singularly perturbed Differential Equations ,1983   **Asymptotic Behavior of Monodromy** Carlos Simpson,2006-11-14 This book concerns the question of how the solution of a system of ODE s varies when the differential equation varies The goal is to give nonzero asymptotic expansions for the solution in terms of a parameter expressing how some coefficients go to infinity A particular classof families of equations is considered where the answer exhibits a new kind of behavior not seen in most work known until now The techniques include Laplace transform and the method of stationary phase and a combinatorial technique for estimating the contributions of terms in an infinite series expansion for the solution Addressed primarily to researchers inalgebraic geometry ordinary differential equations and complex analysis the book will also be of interest to applied mathematicians working on asymptotics of singular perturbations and numerical solution of ODE s   **Introduction to Singular Perturbations** Robert E. Jr. O'Malley,2012-12-02 Introduction to Singular Perturbations provides an overview of the fundamental techniques for obtaining asymptomatic solutions to boundary value problems This text explores singular perturbation techniques which are among the basic tools of several applied scientists This book is organized into eight chapters wherein Chapter 1 discusses the method of matched asymptomatic expansions which has been frequently applied to several physical problems involving singular perturbations Chapter 2 considers the nonlinear initial value problem to illustrate the regular perturbation method and Chapter 3 explains how to construct asymptotic solutions for general linear equations Chapter 4 discusses scalar equations and nonlinear system whereas Chapters 5 and 6 explain the contrasts for initial value problems where the outer expansion cannot be determined without obtaining the initial values of the boundary layer correction Chapters 7 and 8 deal with boundary value problem that arises in the study of adiabatic tubular chemical flow reactors with axial diffusion This monograph is a valuable resource for applied mathematicians engineers researchers students and readers whose interests span a variety of fields   *Difference Methods for Singular Perturbation Problems* Grigory I. Shishkin,Lidia P. Shishkina,2008-09-22 Difference Methods for Singular Perturbation Problems focuses on the development of robust difference schemes for wide classes of boundary value problems It justifies the uniform convergence of these schemes and surveys the latest approaches important for further progress in numerical methods The first part of the book e   *Numerical Analysis of Singular Perturbation Problems* P. W. Hemker,John James Henry Miller,1979 14 lectures by the invited speakers and 14 shorter contributions from the other speakers pref

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