

# K-THEORETIC METHODS IN BIFURCATION THEORY

by J. Pejsachowicz

**Introduction** – Homotopy theoretic methods in several parameter bifurcation theory were developed in the past decade mainly by the work of J.C. Alexander and J. Ize ([2], [17]) among others. The Alexander approach in [2] can be sketched as follows: (see [11] for a rather complete description).

Consider a family  $f_p : \mathbf{R}^n \rightarrow \mathbf{R}^n$  parametrized by  $p \in \mathbf{R}^k$ , with  $f_p(0) = 0$  and let  $L_p$  be the derivative of  $f_p$  at 0. Let  $p_0$  be an isolated point in the set  $\Sigma(f)$  of all parameters at which the derivative  $L_p$  is singular. Restricting the map  $p \mapsto L_p$  to the boundary of a small disk  $D$  centered at  $p_0$  one gets an element  $\gamma_f$  in the homotopy group  $\pi_{k-1}(GL(n))$ . This element is an obstruction to the existence of a deformation of the map  $L : (D, \partial D) \rightarrow (M^{n \times n}, GL(n))$  to a map into  $GL(n)$ . The point  $p_0$  is a bifurcation point of  $f$  provided the image of  $\gamma_f$  by the classical  $J$ -homomorphism is nontrivial.

More general situations e.g. compact vector fields or smooth Fredholm maps can be reduced to the above one by standard arguments. Computation of the relevant invariants are presented in [2], [3], [11]. In [18] Ize, using obstruction theory, completely determines all bifurcation invariants that can be obtained from the behavior of the linearization in a neighborhood of an isolated point. The assumption that  $\Sigma(f)$  is discrete is not generic if  $k > 1$ . At non isolated points one usually restricts the parameters to submanifolds transversal to  $\Sigma(f)$ . (See [19]).

The purpose of the present paper is to discuss similar topics for families of semilinear Fredholm maps (compact perturbations of linear Fredholm operators of index 0) parametrized by compact spaces. This theory presents new and rather interesting aspects reflecting the fact that the space of linear Fredholm operators has non trivial homotopy groups.

Formally our bifurcation invariant is the global version of Alexander's. As such it has different properties. To some extent our approach is inspired by the treatment of families of linear Fredholm operators in [6], [15], [20].

Let  $f_p : X \rightarrow Y$  be a family of semilinear Fredholm maps parametrized by a compact connected CW-complex  $P$  with  $f_p(0) = 0$ , for any  $p$  in  $P$ . Taking the derivative at 0 we get a continuous family  $L = \{L_p\}_{p \in P}$  of Fredholm operators of index 0. The obstruction to deforming such a family to a family of isomorphisms is an element  $\text{Ind } L$  of the reduced Grothendieck group of virtual vector bundles  $\tilde{K}O(P)$ , called the analytical index of the family. Quite naturally our bifurcation invariant is  $J(\text{Ind } L)$ , where now  $J : \tilde{K}O(P) \rightarrow \tilde{J}(P)$  is the generalized  $J$ -homomorphism of Atiyah-Adams. For parameter spaces on which  $J$  is an isomorphism this gives a simple geometric description of bifurcation. Roughly speaking, it arises whenever the family of the derivatives cannot be deformed into  $GL(X, Y)$ .  $J(\text{Ind } L)$  is invariant by compact perturbations and hence it depends only on the principal part of  $L$  (higher order terms in the case of differential

# Methods Of Bifurcation Theory

**M Kubicek, M Marek**



## **Methods Of Bifurcation Theory:**

Methods of Bifurcation Theory S.-N. Chow, J. K. Hale, 2012-12-06 An alternative title for this book would perhaps be *Nonlinear Analysis Bifurcation Theory and Differential Equations* Our primary objective is to discuss those aspects of bifurcation theory which are particularly meaningful to differential equations To accomplish this objective and to make the book accessible to a wider we have presented in detail much of the relevant background audience material from nonlinear functional analysis and the qualitative theory of differential equations Since there is no good reference for some of the material its inclusion seemed necessary Two distinct aspects of bifurcation theory are discussed static and dynamic Static bifurcation theory is concerned with the changes that occur in the structure of the set of zeros of a function as parameters in the function are varied If the function is a gradient then variational techniques play an important role and can be employed effectively even for global problems If the function is not a gradient or if more detailed information is desired the general theory is usually local At the same time the theory is constructive and valid when several independent parameters appear in the function In differential equations the equilibrium solutions are the zeros of the vector field Therefore methods in static bifurcation theory are directly applicable *Methods of Bifurcation Theory* Shui-Nee Chow, 1996 *Computational Methods in Bifurcation Theory and Dissipative Structures* M. Kubicek, M. Marek, 2012-12-06 Dissipative structures is a concept which has recently been used in physics to discuss the formation of structures organized in space and or time at the expense of the energy flowing into the system from the outside The space time structural organization of biological systems starting from the subcellular level up to the level of ecological systems coherent structures in laser and of elastic stability in mechanics instability in hydro plasma physics problems dynamics leading to the development of turbulence behavior of electrical networks and chemical reactors form just a short list of problems treated in this framework Mathematical models constructed to describe these systems are usually nonlinear often formed by complicated systems of algebraic ordinary differential or partial differential equations and include a number of characteristic parameters In problems of theoretical interest as well as engineering practice we are concerned with the dependence of solutions on parameters and particularly with the values of parameters where qualitatively new types of solutions e g oscillatory solutions new stationary states and chaotic attractors appear bifurcate Numerical techniques to determine both bifurcation points and the dependence of steady state and oscillatory solutions on parameters are developed and discussed in detail in this text The text is intended to serve as a working manual not only for students and research workers who are interested in dissipative structures but also for practicing engineers who deal with the problems of constructing models and solving complicated nonlinear systems

*Bifurcation Theory And Methods Of Dynamical Systems* Maoan Han, Dingjun Luo, Xian Wang, Deming Zhu, 1997-11-29 Dynamical bifurcation theory is concerned with the changes that occur in the global structure of dynamical systems as parameters are varied This book makes recent research in bifurcation theory of dynamical systems accessible to researchers

interested in this subject In particular the relevant results obtained by Chinese mathematicians are introduced as well as some of the works of the authors which may not be widely known The focus is on the analytic approach to the theory and methods of bifurcations The book prepares graduate students for further study in this area and it serves as a ready reference for researchers in nonlinear sciences and applied mathematics Elements of Applied Bifurcation Theory Yuri Kuznetsov,2013-03-09 The years that have passed since the publication of the first edition of this book proved that the basic principles used to select and present the material made sense The idea was to write a simple text that could serve as a serious introduction to the subject Of course the meaning of simplicity varies from person to person and from country to country The word introduction contains even more ambiguity To start reading this book only a moderate knowledge of linear algebra and calculus is required Other preliminaries qualified as elementary in modern mathematics are explicitly formulated in the book These include the Fredholm Alternative for linear systems and the multidimensional Implicit Function Theorem Using these very limited tools a framework of notions results and methods is gradually built that allows one to read and possibly write scientific papers on bifurcations of nonlinear dynamical systems Among other things progress in the sciences means that mathematical results and methods that once were new become standard and routinely used by the research and development community Hopefully this edition of the book will contribute to this process The book's structure has been kept intact Most of the changes introduced reflect recent theoretical and software developments in which the author was involved Important changes in the third edition can be summarized as follows A new section devoted to the fold flip bifurcation for maps has appeared in Chapter 9 *Bifurcation Theory and Methods of Dynamical Systems* Dingjun Luo,1997 Dynamical bifurcation theory is concerned with the changes that occur in the global structure of dynamical systems as parameters are varied This book makes recent research in bifurcation theory of dynamical systems accessible to researchers interested in this subject In particular the relevant results obtained by Chinese mathematicians are introduced as well as some of the works of the authors which may not be widely known The focus is on the analytic approach to the theory and methods of bifurcations The book prepares graduate students for further study in this area and it serves as a ready reference for researchers in nonlinear sciences and applied mathematics *Perturbation Methods, Bifurcation Theory and Computer Algebra* Richard H. Rand,Dieter Armbruster,2012-12-06 Perturbation methods have always been an important tool for treating nonlinear differential equations Now the drudgery associated with them has been eliminated This book offers computer algebra MACSYMA programs which implement the most popular perturbation methods Not only does this avoid the errors associated with hand computation but the increase in efficiency permits more complicated problems to be tackled This book is useful both for the beginner learning perturbation methods for the first time as well as for the researcher Methods covered include Lindstedt's method center manifolds normal forms two variable expansion method method of multiple scales averaging Lie transforms and Liapunov Schmidt reduction For each method the book includes an introduction and some

example problems solved both by hand and by machine The examples feature common bifurcations such as the pitchfork and the Hopf The MACSYMA code for each method is given and suggested exercises are provided at the end of each Chapter An Appendix offers a brief introduction to MACSYMA

### **Group Theoretic Methods in Bifurcation Theory** David H.

Sattinger,2006-11-15 Ischemia and Loss of Vascular Autoregulation in Ocular and Cerebral Diseases A New Perspective presents evidence that ischemia and loss of autoregulation of blood flow are associated with the onset of the major ocular and cerebral diseases including macular degeneration diabetic retinopathy low and normal tension open angle glaucoma stroke and Alzheimer s disease Recognition of these vascular changes underline the critical need for clinicians to monitor blood flow and autoregulation to improve early diagnosis and to optimize therapies of ocular and cerebral vascular diseases The text brings to clinicians in Ophthalmology Neurology Medicine Optometry and Geriatrics decisive guidance on the practical aspects for early diagnosis and treatment of ocular and cerebral diseases The author brings together in a concise form the progress made over the span of his career and provides new perspectives and understanding of the fluid circulations of the eye and the brain In addition he explains the new analytical technologies that made the new concepts possible The physiological and functional importance of blood flow autoregulation in the eye and in the brain in minimizing the progression of pathology including the ischemia resulting from stenosis of the internal carotid artery and stroke are also presented ABOUT THE AUTHOR Dr Langham was born in London England In 1947 he joined the Ophthalmological Research Unit newly formed by the Medical Research Council of the United Kingdom under the direction of Sir Stewart Duke Elder In 1956 the author enjoyed a research fellowship at Harvard University After returning to England for a time he accepted a position of Associate Professor of Ophthalmology and Director of Research at the Wilmer Ophthalmological Institute of the Johns Hopkins Hospital and Medical school in 1959 There he initiated a program in which all residents spent time engaged in research This productive interaction between the disciplines led to many important clinical diagnostic and therapeutic advances

**Continuation Techniques and Bifurcation Problems** MITTELMANN,FISCHER,2013-11-21 The analysis of parameter dependent nonlinear has received much attention in recent years Numerical continuation techniques allow the efficient computation of solution branches in a one parameter problem In many cases continuation procedures are used as part of a more complete analysis of a nonlinear problem based on bifurcation theory and singularity theory These theories contribute to the understanding of many nonlinear phenomena in nature and they form the basis for various analytical and numerical tools which provide qualitative and quantitative results about nonlinear systems In this issue we have collected a number of papers dealing with continuation techniques and bifurcation problems Readers familiar with the notions of continuation and bifurcation will find recent research results addressing a variety of aspects in this issue Those who intend to learn about the field or a specific topic in it may find it useful to first consult earlier literature on the numerical treatment of these problems together with some theoretical background The papers in this issue fall naturally into different groups

**Elements of Applied Bifurcation Theory** Yuri A. Kuznetsov, 2013-03-09 During the last few years several good textbooks on nonlinear dynamics have appeared for graduate students in applied mathematics. It seems however that the majority of such books are still too theoretically oriented and leave many practical issues unclear for people intending to apply the theory to particular research problems. This book is designed for advanced undergraduate or graduate students in mathematics who will participate in applied research. It is also addressed to professional researchers in physics, biology, engineering, and economics who use dynamical systems as modeling tools in their studies. Therefore, only a moderate mathematical background in geometry, linear algebra, analysis, and differential equations is required. A brief summary of general mathematical terms and results that are assumed to be known in the main text appears at the end of the book. Whenever possible, only elementary mathematical tools are used. For example, we do not try to present normal form theory in full generality; instead, we develop only the portion of the technique sufficient for our purposes. The book aims to provide the student or researcher with both a solid basis in dynamical systems theory and the necessary understanding of the approaches, methods, results, and terminology used in the modern applied mathematics literature. A key theme is that of topological equivalence and codimension, or what one may expect to occur in the dynamics with a given number of parameters allowed to vary.

**Bifurcation Theory** Ale Jan Homburg, Jürgen Knobloch, 2024-12-02 This textbook provides a thorough overview of bifurcation theory. Assuming some familiarity with differential equations and dynamical systems, it is suitable for use on advanced undergraduate and graduate level and can in particular be used for a graduate course on bifurcation theory. The book combines a solid theoretical basis with a detailed description of classical bifurcations. It is organized in chapters on local, nonlocal, and global bifurcations, a number of appendices develop the toolbox for the study of bifurcations. The discussed local bifurcations include saddle node and Hopf bifurcations, as well as the more advanced Bogdanov-Takens and Neimark-Sacker bifurcations. The book also covers nonlocal bifurcations, discussing various homoclinic bifurcations and it surveys global bifurcations and phenomena such as intermittency and period doubling cascades. The book develops a broad range of complementary techniques, both geometric and analytic, for studying bifurcations. Techniques include normal form methods, center manifold reductions, the Lyapunov-Schmidt construction, cross-coordinate constructions, Melnikov's method, and Lin's method. Full proofs of the results are provided, also for the material in the appendices. This includes proofs of the stable manifold theorem, the center manifold theorem, and of Lin's method for studying homoclinic bifurcations.

*Elements of Applied Bifurcation Theory* Yuri Kuznetsov, 1998-09-18 Providing readers with a solid basis in dynamical systems theory, as well as explicit procedures for application of general mathematical results to particular problems, the focus here is on efficient numerical implementations of the developed techniques. The book is designed for advanced undergraduates or graduates in applied mathematics, as well as for Ph.D. students and researchers in physics, biology, engineering, and economics who use dynamical systems as model tools in their studies. A moderate mathematical background is assumed, and whenever

possible only elementary mathematical tools are used This new edition preserves the structure of the first while updating the context to incorporate recent theoretical developments in particular new and improved numerical methods for bifurcation analysis Numerical Methods for Bifurcations of Dynamical Equilibria Willy J. F. Govaerts,2000-01-01 Dynamical systems arise in all fields of applied mathematics The author focuses on the description of numerical methods for the detection computation and continuation of equilibria and bifurcation points of equilibria of dynamical systems This subfield has the particular attraction of having links with the geometric theory of differential equations numerical analysis and linear algebra

**Continuation and Bifurcations: Numerical Techniques and Applications** Dirk Roose,Bart De Dier,Alastair Spence,2012-12-06 Proceedings of the NATO Advanced Research Workshop Leuven Belgium September 18 22 1989

*Methods In Equivariant Bifurcations And Dynamical Systems* Pascal Chossat,Reiner Lauterbach,2000-02-28 This invaluable book presents a comprehensive introduction to bifurcation theory in the presence of symmetry an applied mathematical topic which has developed considerably over the past twenty years and has been very successful in analysing and predicting pattern formation and other critical phenomena in most areas of science where nonlinear models are involved like fluid flow instabilities chemical waves elasticity and population dynamics The book has two aims One is to expound the mathematical methods of equivariant bifurcation theory Beyond the classical bifurcation tools such as center manifold and normal form reductions the presence of symmetry requires the introduction of the algebraic and geometric formalism of Lie group theory and transformation group methods For the first time all these methods in equivariant bifurcations are presented in a coherent and self consistent way in a book The other aim is to present the most recent ideas and results in this theory in relation to applications This includes bifurcations of relative equilibria and relative periodic orbits for compact and noncompact group actions heteroclinic cycles and forced symmetry breaking perturbations Although not all recent contributions could be included and a choice had to be made a rather complete description of these new developments is provided At the end of every chapter exercises are offered to the reader **Topological Methods in Bifurcation Theory**

,1985 Computational Methods in Bifurcation Theory and Dissipative Structures M Kubicek,M Marek,1983-11-01 **A Comparison of Two Constructive Methods for Bifurcation Theory** David Joseph Mescheloff,1973 **Numerical Methods for Bifurcation Problems and Large-Scale Dynamical Systems** Eusebius Doedel,Laurette S.

Tuckerman,2012-12-06 The Institute for Mathematics and its Applications IMA devoted its 1997 1998 program to Emerging Applications of Dynamical Systems Dynamical systems theory and related numerical algorithms provide powerful tools for studying the solution behavior of differential equations and mappings In the past 25 years computational methods have been developed for calculating fixed points limit cycles and bifurcation points A remaining challenge is to develop robust methods for calculating more complicated objects such as higher codimension bifurcations of fixed points periodic orbits and connecting orbits as well as the calculation of invariant manifolds Another challenge is to extend the applicability of

algorithms to the very large systems that result from discretizing partial differential equations Even the calculation of steady states and their linear stability can be prohibitively expensive for large systems e g  $10^3$   $10^6$  equations if attempted by simple direct methods Several of the papers in this volume treat computational methods for low and high dimensional systems and in some cases their incorporation into software packages A few papers treat fundamental theoretical problems including smooth factorization of matrices self organized criticality and unfolding of singular heteroclinic cycles Other papers treat applications of dynamical systems computations in various scientific fields such as biology chemical engineering fluid mechanics and mechanical engineering

Numerical Methods for Bifurcation Problems

KÜPPER,MITTELMANN,WEBER,2013-11-27

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