

# 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

**Pascal Chossat, Reiner Lauterbach**



## 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 *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

*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.

#### **Group Theoretic Methods in Bifurcation Theory**

David H. Sattinger, 2014-01-15

**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.

#### **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.

#### **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

### **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

*Computational Methods in Bifurcation Theory and Dissipative Structures* M Kubicek,M Marek,1983-11-01

### **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

*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

*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 developing 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

**Computational Methods in Bifurcation Theory and Dissipative Structures** Milan Kubiček, M. Marek, 1983

**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 of the center manifold theorem and of Lin's method for

studying homoclinic bifurcations      **A Comparison of Two Constructive Methods for Bifurcation Theory** David Joseph  
 Mescheloff, 1973      *Topological Methods in Bifurcation Theory*, 1985      **Numerical Bifurcation Analysis of Maps**  
 Iñaki Aleksandrovich Kuznetsov, Yuri A. Kuznetsov, Hil G. E. Meijer, 2019-03-28 Combines a systematic analysis of  
 bifurcations of iterated maps with concrete MATLAB implementations and applications      *Continuation and Bifurcations:*  
*Numerical Techniques and Applications* Dirk Roose, Bart De Dier, Alastair Spence, 2012-12-06 Proceedings of the NATO  
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