

# Rates for maps and flows in a deterministic multidimensional weak invariance principle

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## Abstract

We present the first rates of convergence to an  $N$ -dimensional Brownian motion when  $N \geq 2$  for discrete and continuous time dynamical systems. Additionally, we provide the first rates for continuous time in any dimension. Our results hold for nonuniformly hyperbolic and expanding systems, such as Axiom A flows, suspensions over a Young tower with exponential tails, and some classes of intermittent solenoids.

## 1 Introduction

The study of statistical laws for dynamical systems is a widely explored area that attracted the attention of a rich research community, starting from the work of Bowen, Ruelle and Sinai in the 1970s. This paper provides quantitative estimates on the number of iterations of a hyperbolic/expanding<sup>†</sup> system to accurately approximate Brownian motion. In particular, we focus on the rates of convergence for a deterministic version of the classical functional central limit theorem of Donsker [15]. In the following, we will refer to this as the weak invariance principle (WIP). Such a result was proved for numerous nonuniformly hyperbolic maps in [20] and for uniformly hyperbolic flows in [14]. More recent developments in this direction for a nonuniformly hyperbolic setting are [6, 18, 30, 33, 34].

A natural consequence of the WIP is the central limit theorem, where the rates of convergence are commonly referred to as Berry-Esseen estimates. Sharp results in this direction for uniformly and nonuniformly hyperbolic diffeomorphisms were found respectively in [10] and [19]. In the continuous time literature, [37] was the first to provide Berry-Esseen estimates; these are of the order of  $\mathcal{O}(n^{-1/4+\varepsilon})$ ,  $\varepsilon > 0$ , in the Prokhorov metric for a billiard flow with finite horizon.

For the WIP, Antoniou and Melbourne [3] proved a convergence rate of  $\mathcal{O}(n^{-1/4+\delta})$  in the Prokhorov metric for nonuniformly hyperbolic maps, while Liu and Wang [26] proved the same rate in the  $q$ -Wasserstein metric for  $q > 1$ . Here,  $\delta > 0$  depends on the degree of nonuniformity and it gets smaller for greater  $q$ ; it can be chosen arbitrarily small if the system has exponential tails. The methods of [3, 26] are based on a generalisation [22] of the martingale-coboundary decomposition technique of Gordin [17], which allows to apply

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<sup>†</sup>For the remainder of the introduction, we write "hyperbolic" instead of "hyperbolic/expanding".

# Maps Of Invariance

**Àlex Haro, Marta Canadell, Jordi-Lluís  
Figueras, Alejandro Luque, Josep Maria  
Mondelo**

## **Maps Of Invariance:**

**Continuous And Discontinuous Piecewise-smooth One-dimensional Maps: Invariant Sets And Bifurcation Structures** Viktor Avrutin, Laura Gardini, Iryna Sushko, Fabio Tramontana, 2019-05-28 The investigation of dynamics of piecewise smooth maps is both intriguing from the mathematical point of view and important for applications in various fields ranging from mechanical and electrical engineering up to financial markets In this book we review the attracting and repelling invariant sets of continuous and discontinuous one dimensional piecewise smooth maps We describe the bifurcations occurring in these maps border collision and degenerate bifurcations as well as homoclinic bifurcations and the related transformations of chaotic attractors and survey the basic scenarios and structures involving these bifurcations In particular the bifurcation structures in the skew tent map and its application as a border collision normal form are discussed We describe the period adding and incrementing bifurcation structures in the domain of regular dynamics of a discontinuous piecewise linear map and the related bandcount adding and incrementing structures in the domain of robust chaos Also we explain how these structures originate from particular codimension two bifurcation points which act as organizing centers In addition we present the map replacement technique which provides a powerful tool for the description of bifurcation structures in piecewise linear and other form of invariant maps to a much further extent than the other approaches

**The Parameterization Method for Invariant Manifolds** Àlex Haro, Marta Canadell, Jordi-Lluís Figueras, Alejandro Luque, Josep Maria Mondelo, 2016-04-18 This monograph presents some theoretical and computational aspects of the parameterization method for invariant manifolds focusing on the following contexts invariant manifolds associated with fixed points invariant tori in quasi periodically forced systems invariant tori in Hamiltonian systems and normally hyperbolic invariant manifolds This book provides algorithms of computation and some practical details of their implementation The methodology is illustrated with 12 detailed examples many of them well known in the literature of numerical computation in dynamical systems A public version of the software used for some of the examples is available online The book is aimed at mathematicians scientists and engineers interested in the theory and applications of computational dynamical systems

**Management of Standard Graphic Symbols in a Computer-aided Design and Drafting Environment Using Neural Network Approaches** Der-Shung Yang, 1994 Abstract Computer Aided Design and Drafting CADD systems have become prevalent for producing building design drawings An ultimate goal of CADD systems is to automate analyses and communication of high level design information extracted from CADD drawings a difficult task because of the lack of CADD standards Using standard graphic symbols attached with symbolic information can help but locating symbols in large libraries is difficult AUGURS is a new interactive tool designed to assist CADD users in utilizing standard symbols The task of recognizing symbols sketched by CADD users differs from traditional pattern recognition problems in several ways Standard libraries have over 1000 symbols grouped into seven disciplines The large symbol set makes training data difficult to obtain

Since AUGURS is embedded in the CADD system it must be efficient and compact Also it needs to handle irregular distortion in symbols sketched by users These difficulties are lessened by the special output format that requires AUGURS to perform only admissible recognition classifying the input to a small set of plausible symbols The symbol recognition program in AUGURS is a neural network similar to the Neocognitron but is more compact and efficient and having better recognition performance The main thrust of the AUGURS approach is a novel network structure encoded with general knowledge balancing the discriminant power and the noise tolerance of the network To handle large symbol sets another thrust of the AUGURS approach is to construct a network by first building an integrated network from the internal structures of smaller networks trained on sub tasks and then pruning unnecessary components from this integrated network This research contains an extensive empirical study of numerous related work varying conditions and parameters The results demonstrate the superiority of the AUGURS approach over many alternatives including Zipcode Nets an unconstrained network networks using such invariant features as Zernike moments pseudo Zernike moments normalized moments and Fourier Mellin descriptors the Integrated Neural Network and the connectionist gluing approach A practicality analysis shows that AUGURS can handle around 100 symbols about the size of a discipline library To enable AUGURS to handle even more symbols future work is planned to augment it with domain specific knowledge and other improvements

**History of Topology** I.M. James, 1999-08-24 Topology for many years has been one of the most exciting and influential fields of research in modern mathematics Although its origins may be traced back several hundred years it was Poincar who gave topology wings in a classic series of articles published around the turn of the century While the earlier history sometimes called the prehistory is also considered this volume is mainly concerned with the more recent history of topology from Poincar onwards As will be seen from the list of contents the articles cover a wide range of topics Some are more technical than others but the reader without a great deal of technical knowledge should still find most of the articles accessible Some are written by professional historians of mathematics others by historically minded mathematicians who tend to have a different viewpoint

**American Journal of Mathematics Pure and Applied** ,1926 **Transactions of the American Mathematical Society** American Mathematical Society, 1917 Monthly journal devoted entirely to research in pure and applied mathematics and in general includes longer papers than those in the Proceedings of the American Mathematical Society American Journal of Mathematics ,1924 The American Journal of Mathematics publishes research papers and articles of broad appeal covering the major areas of contemporary mathematics *Invariants in Chain Complexes of Graphs* Ferenc Gerlits, 2002

**Family Gromov-Witten Invariants for Kähler Surfaces** Junho Lee, 2001 **Geometry in the Neighborhood of Invariant Manifolds of Maps and Flows and Linearization** Urs Kirchgraber, K. J. Palmer, 1990 Proceedings of the National Academy of Sciences of the United States of America National Academy of Sciences (U.S.), 1926 **Proceedings of the West Virginia Academy of Science** West Virginia Academy of Science, 1926 List of members in v 2 *Rates for*

*Maps and Flows in a Deterministic Multidimensional Weak Invariance Principle* Nicolò Paviato, 2022      *Bulletin of the American Mathematical Society* American Mathematical Society, 1921      *ACM SIGGRAPH* 88, 1988      *Functions of a Complex Variable* Edgar Jerome Townsend, 1915      *Invariant Manifolds, Entropy and Billiards. Smooth Maps with Singularities* Anatole Katok, Jean-Marie Strelcyn, 2006-12-08      *Revue Semestrielle Des Publications Mathématiques*, 1927

**Pacific Journal of Mathematics**, 1979      *Dynamic Economic Theory* Jean-Pierre Aubin, 1997-05-20 This book is intended to provide economists with mathematical tools necessary to handle the concepts of evolution under uncertainty and adaption arising in economics pursuing the Arrow Debreu Hahn legacy It applies the techniques of viability theory to the study of economic systems evolving under contingent uncertainty faced with scarcity constraints and obeying various implementation of the inertia principle The book illustrates how new tools can be used to move from static analysis built on concepts of optima equilibria and attractors to a contingent dynamic framework

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