

# Introduction to Chaos in Deterministic Systems

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## 1. Introduction

The scope of this teaching package is to make a brief introduction to some notions and properties of chaotic systems. We first make a brief introduction to chaos in general and then we show some important properties of chaotic systems using the logistic map and its bifurcation diagram. We also show the universality found in “the route to chaos”.

The user is only required to have notions of algebra, so it is quite accessible. The formal basis of chaos theory are not covered in this introduction, but are pointed out for the reader interested in them. Therefore, this package is also useful for people who are interested in going deep into the mathematical theories, because it is a simple introduction of the terminology, and because it points out which are the original sources of information (so there is no danger in falling in the trap of “Learn Chaos in 48 hours” or “Bifurcation Diagrams for Dummies”).

The included exercises are suggested for consolidating the covered topics. The on-line resources are highly recommended for extending this brief induction.

## 2. Chaos

The study of chaotic dynamics in deterministic systems has become very popular in the past few decades, emerging from the study of **non-linear dynamics**. Perhaps it is because of the amazing findings that the study of chaotic systems has delivered. First, it would be natural to think that if a system is deterministic, its behaviour should be easily predicted. But there are systems where their behaviour turns out to be non-predictable: not because of lack of determinism, but because the complexity of the dynamics require a precision that is unable to be computed. This can be seen in systems where very similar initial conditions yield very different behaviours. Thus, let's say if we have the initial states 2.1234567890 and 2.1234567891, after some time the system will be for the first case in 3.5 and in the other in -1.7. So, no matter how much precision we have, the most minimal differences will tend in the long time to very different results. This is because there is an exponential divergence of the trajectories of the system (This can formally be measured with **Lyapunov exponents**).

Another interesting property of chaotic systems are **strange attractors**<sup>1</sup>. If one thinks of chaotic dynamics, it would be easy to assume that the dynamics follow no pattern. But if we

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<sup>1</sup>An attractor is a part of the state-space (which is the set of all possible states of a system) which “pulls” the dynamics into it. For example, a simple pendulum with friction has a **stable attractor** in the bottom of the vertical axis, because wherever the pendulum is, it will end at some time in that point. But there is an **unstable attractor** in the top of the vertical axis, because if that is the initial condition, in theory the pendulum would stay up there, but the most minimal perturbation would move the pendulum out of the unstable attractor. The unstable attractor repels the dynamics of the system.

# Deterministic Chaos An Introduction

**Harry Thomas**



## **Deterministic Chaos An Introduction:**

**Deterministic Chaos** Heinz Georg Schuster, Wolfram Just, 2006-03-06 A new edition of this well established monograph this volume provides a comprehensive overview over the still fascinating field of chaos research The authors include recent developments such as systems with restricted degrees of freedom but put also a strong emphasis on the mathematical foundations Partly illustrated in color this fourth edition features new sections from applied nonlinear science like control of chaos synchronisation of nonlinear systems and turbulence as well as recent theoretical concepts like strange nonchaotic attractors on off intermittency and spatio temporal chaotic motion

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**Deterministic Chaos -an Introduction** H.G. Schuster, *Chaos, Dynamics, and Fractals* Joseph L. McCauley, 1994-05-26 This book develops deterministic chaos and fractals from the standpoint of iterated maps but the emphasis makes it very different from all other books in the field It provides the reader with an introduction to more recent developments such as weak universality multifractals and shadowing as well as to older subjects like universal critical exponents devil s staircases and the Farey tree The author uses a fully discrete method a theoretical computer arithmetic because finite but not fixed precision cannot be avoided in computation or experiment This leads to a more general formulation in terms of symbolic dynamics and to the idea of weak universality The connection is made with Turing s ideas of computable numbers and it is explained why the continuum approach leads to predictions that are not necessarily realized in computation or in nature whereas the discrete approach yields all possible histograms that can be observed or computed

**Introduction to Chaos and Coherence** J. Froyland, 2019-10-02 This book provides an introduction to the theory of chaotic systems and demonstrates how chaos and coherence are interwoven in some of the models exhibiting deterministic chaos It is based on the lecture notes for a short course in dynamical systems theory given at the University of Oslo

Deterministic Chaos N. Kumar, 1996 This book defines describes and prescribe the newly emerged paradigm of complexity of change how a simple system ruled by a deterministic law can evolve in a manner too complex to predict in detail in the long run After explaining through examles the underlying idea of sensitive depenence on initial conditions caused by non linearity id describes the powerful qualitative techniques

**Computational Turbulent Incompressible**

**Flow** Johan Hoffman, Claes Johnson, 2007-01-05 This is Volume 4 of the book series of the Body and Soul mathematics education reform program It presents a unified new approach to computational simulation of turbulent flow starting from the

general basis of calculus and linear algebra of Vol 1 3 The book puts the Body and Soul computational finite element methodology in the form of General Galerkin G2 up against the challenge of computing turbulent solutions of the inviscid Euler equations and the Navier Stokes equations with small viscosity This is an outstanding textbook presenting plenty of new material with an excellent pedagogical approach

**Mathematics for Physicists** Alexander Altland, Jan von Delft, 2019-02-14 This textbook is a comprehensive introduction to the key disciplines of mathematics linear algebra calculus and geometry needed in the undergraduate physics curriculum Its leitmotiv is that success in learning these subjects depends on a good balance between theory and practice Reflecting this belief mathematical foundations are explained in pedagogical depth and computational methods are introduced from a physicist's perspective and in a timely manner This original approach presents concepts and methods as inseparable entities facilitating in depth understanding and making even advanced mathematics tangible The book guides the reader from high school level to advanced subjects such as tensor algebra complex functions and differential geometry It contains numerous worked examples info sections providing context biographical boxes several detailed case studies over 300 problems and fully worked solutions for all odd numbered problems An online solutions manual for all even numbered problems will be made available to instructors

**Earth and Mind** Cathryn A. Manduca, David W. Mogk, 2006-01-01

*Introduction to Chaos and Coherence* J Froyland, 2022-01-26 This book provides an introduction to the theory of chaotic systems and demonstrates how chaos and coherence are interwoven in some of the models exhibiting deterministic chaos It is based on the lecture notes for a short course in dynamical systems theory given at the University of Oslo

*Nonlinear Dynamics in Solids* Harry Thomas, 2012-12-06 This volume contains the notes of lectures given at the school on Nonlinear Dynamics in Solids held at the Physikzentrum Bad Honnef 2 6 October 1989 under the patronage of the Deutsche Physikalische Gesellschaft Nonlinear dynamics has become a highly active research area owing to many interesting developments during the last three decades in the theoretical analysis of dynamical processes in both Hamiltonian and dissipative systems Research has been focused on a variety of problems such as the characteristics of regular and chaotic motion in Hamiltonian dynamics the problem of quantum chaos the formation and properties of solitary spatio-temporal structures the occurrence of strange attractors in dissipative systems and the bifurcation scenarios leading to complex time behaviour Until recently predictions of the theory have been tested predominantly on instabilities in hydrodynamic systems where many interesting experiments have provided valuable input and have led to a fruitful interaction between experiment and theory Fluid systems are certainly good candidates for performing clean experiments free from disturbing influences with fluids compared to solids it is simpler to prepare good samples the relevant length and time scales are in easily accessible ranges and it is possible to do measurements inside the fluid because it can be filled in after the construction of the apparatus Further the theory describing the macroscopic dynamics of fluids is well established and contains only very few parameters all of which have well known values

**Mainstream Mathematical Economics in the**

**20th Century** PierCarlo Nicola, 2013-03-14 To write everything about nothing or to write nothing about everything this is the problem Anonym circa 1996 97 The first idea to write a book on Mathematical Economics more or less ordered in a historical sequence occurred to me in 1995 when I was asked by Istituto dell'Enciclopedia Italiana to write the entry Storia dell'economia 1 2 matematica for the collective work Storia del XX Secolo I thought that it would be interesting to elaborate on the text presented to the editors to turn it into a book aiming at giving a panorama of what in my opinion are the main 20th century contributions to mathematical economics Of course only a narrow set of the contributions made by economic theorists could be included both for space limitations and necessity because 3 of the limited competence of any single author For instance I have paid very limited attention to what is now called Macroeconomics and also to Game Theory which actually has grown so much as to acquire scientific independence as a living branch of applied mathematics For the same reason I have also left completely untouched such fields as Mathematical Finance Public Economics Theory of Taxation etc I have always based my presentation on published material only assuming that what is contained in working papers still waits to be confirmed possibly in the first years of the 21st century Progress of Theoretical Physics, 2003 *Data-Centric Business and Applications* Tamara Radivilova, Dmytro Ageyev, Natalia Kryvinska, 2020-06-20 This book addresses the challenges and opportunities of information data processing and management It also covers a range of methods techniques and strategies for making it more efficient approaches to increasing its usage and ways to minimize information data loss while improving customer satisfaction Information and Communication Technologies ICTs and the Service Systems associated with them have had an enormous impact on businesses and our day to day lives over the past three decades and continue to do so This development has led to the emergence of new application areas and relevant disciplines which in turn present new challenges and opportunities for service system usage The book provides practical insights into various aspects of ICT technologies for service systems Techniques for information data processing and modeling in service systems Strategies for the provision of information data processing and management Methods for collecting and analyzing information data Applications benefits and challenges of service system implementation Solutions to increase the performance of various service systems using the latest ICT technologies **Subsurface Contamination Remediation** Edgar Berkey, Tiffany Zachry, 2005 This book presents leading edge research on subsurface contamination remediation being conducted through the U S Department of Energy Environmental Management Science Program EMSP addressing 1 remedial science and technology 2 characterization fate and transport and 3 environmental sensing and monitoring *An Exploration of Dynamical Systems and Chaos* John H. Argyris, Gunter Faust, Maria Haase, Rudolf Friedrich, 2015-04-24 This book is conceived as a comprehensive and detailed text book on non linear dynamical systems with particular emphasis on the exploration of chaotic phenomena The self contained introductory presentation is addressed both to those who wish to study the physics of chaotic systems and non linear dynamics intensively as well as those who are curious to learn more

about the fascinating world of chaotic phenomena Basic concepts like Poincaré section iterated mappings Hamiltonian chaos and KAM theory strange attractors fractal dimensions Lyapunov exponents bifurcation theory self similarity and renormalisation and transitions to chaos are thoroughly explained To facilitate comprehension mathematical concepts and tools are introduced in short sub sections The text is supported by numerous computer experiments and a multitude of graphical illustrations and colour plates emphasising the geometrical and topological characteristics of the underlying dynamics This volume is a completely revised and enlarged second edition which comprises recently obtained research results of topical interest and has been extended to include a new section on the basic concepts of probability theory A completely new chapter on fully developed turbulence presents the successes of chaos theory its limitations as well as future trends in the development of complex spatio temporal structures This book will be of valuable help for my lectures Hermann Haken Stuttgart This text book should not be missing in any introductory lecture on non linear systems and deterministic chaos Wolfgang Kinzel Würzburg This well written book represents a comprehensive treatise on dynamical systems It may serve as reference book for the whole field of nonlinear and chaotic systems and reports in a unique way on scientific developments of recent decades as well as important applications Joachim Peinke Institute of Physics Carl von Ossietzky University Oldenburg Germany

**Deterministic Chaos** N. Kumar, Encyclopedia of Physical Science and Technology Robert A. Meyers, 2002 Following in the footsteps of the earlier editions hundreds of the most respected scientists and engineers participated in the creation of this new edition including many Nobel Laureates The articles are in depth yet accessible and address all of the key areas of physical science including aeronautics astronomy chemistry communications computers earth sciences electronics engineering materials science mathematics nuclear technology physics power systems propulsion and space technology Midwest *American Journal of Physics*, 1997 *Proceedings of the Royal Society of London* Royal Society (Great Britain), 1990

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