

Deterministic Chaos

Introduction

This is a project based on the subject of chaos theory. The aim of this project was to investigate whether for different chaotic systems the Feigenbaum number and Lyapunov exponent are universal. This involves producing computational programs capable of plotting bifurcation diagrams, Lyapunov exponent plots and careful analysis of the bifurcation diagram to calculate the Feigenbaum number for each map. Using these results comparisons between the different systems can be made to determine the mutual or different properties.

Methods

Wolfram Mathematica was used to create computational programs capable of producing the BF diagrams and LE plots displayed.

A bifurcation diagram provides a visual representation of how a dynamical system evolves through small changes of a parameter, these bifurcations are important scientifically as they provide representation of instabilities¹. A mathematical physicist Mitchell Feigenbaum explored the route to chaos of the logistic map and found a relationship between the period-doublings which occur via the bifurcations. The relationship was a ratio of the consecutive values of control parameter " μ " where the bifurcation splitting occurs². The equation for calculating the FB number is,

$$\delta = \lim_{n \rightarrow \infty} \frac{\mu_n - \mu_{n-1}}{\mu_{n+1} - \mu_n}$$

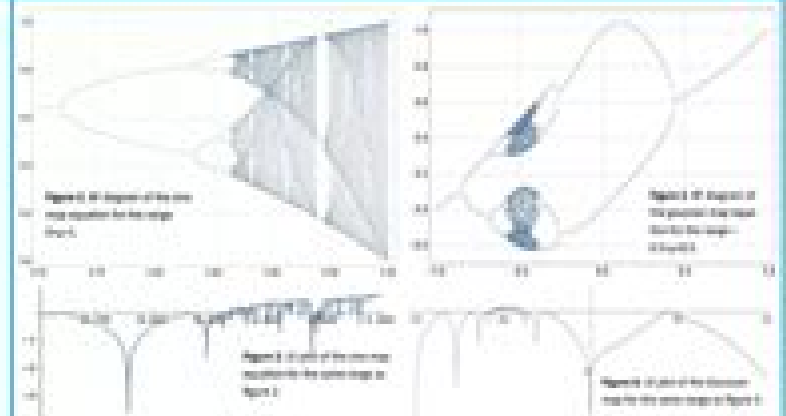
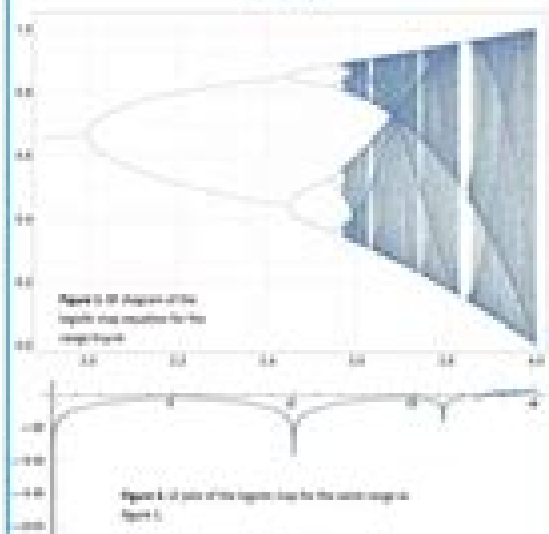
Where " n " is the order of the splittings and each μ_n corresponding to its order. A Lyapunov stable point is where that all trajectories near that fixed point remain close to it for all time.

The Lyapunov exponent is a measurement of the sensitive dependence on the initial conditions of the system and a plot of the Lyapunov exponent for changes in the control parameter gives a measure of whether this system is chaotic (positive exponent) or non-chaotic (negative exponent)³. The LE is defined as,

$$\lambda = \lim_{n \rightarrow \infty} \left(\frac{1}{n} \sum_{i=0}^{n-1} \ln |f'(x_i)| \right)$$

Where " n " is the number of iterations, $f'(x)$ is the first differential of the maps equation applied to the value of " x " at that point in the list. A chaotic system is one which seems completely random but in fact is deterministic, highly sensitive to initial conditions and one small error in a measurement of the initial condition produces an error which grows exponentially making the system un-deterministic or unpredictable. This effect is also called the butterfly effect and can be seen in many dynamical systems such as the weather, climate, pendulum, populations and more⁴.

Results



The sine map and the logistic map look extremely similar for the range $0 < \mu < 1$ and $0 < \mu < 1$ respectively, both are smooth, concave down and have a single maximum (unimodal). Both maps have the same vertical scale but differing horizontal scales, the difference in the horizontal scale is a factor of 4 due to the maximum of the quadratic line for the sine plot being μ and μ^2 for the logistic map. The periodic windows occur in the same order and with the same relative sizes. The biggest difference between the two maps in these regimes is the period doublings occur later in the logistic map and are thinner⁵. The Gauss map is significantly different to the other two maps in both BF diagram and LE plot, the biggest characteristic of this map is that it reaches a maximum chaotic behaviour and reverses back to periodic behaviour. Only a small area of the Gaussian LE plot is above zero (chaotic).

Conclusion

Maps of the form $x_{n+1} = \mu f(x_n)$ where $f(0) = f(1) = 0$ display the same structure on a bifurcation diagram. As μ is varied, the order in which stable period solutions appear is independent of the unimodal map iterated⁶. The LE is very much dependent on the system at hand, it measures where the system is stable or unstable so for example a damped oscillator will be stable at different points to the climate of the Earth. The LE is also very much dependent on initial conditions, this displays the nature of the un-deterministic nature of chaos. Feigenbaum came up with a theory on why the constant he discovered occurs and it is based on a theory called Renormalization. The renormalization theory is based on the self-similarity of larger the "fractal" structure of the maps where the smaller branches look like the earlier branches except they are scaled down in both the x and μ directions. This theory explains how the FB number is universal for unimodal maps with a single maximum. This theory could be applied to other shaped maps.

Deterministic Chaos An Introduction

Alexander Altland, Jan von Delft



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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, **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

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

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

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

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

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 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 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

Proceedings of the Royal Society of London Royal Society (Great Britain), 1990

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

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 *Progress of Theoretical Physics*, 2003 **American Journal of Physics**, 1997 **Proceedings, 1995 International Symposium on Nonlinear Theory and Its Applications**, 1995 **Advances and Problems in the Philosophy of Technology** Hans Lenk, Matthias Maring, Académie internationale de philosophie des sciences. Conference, 2001 The Proceedings of the Karlsruhe Academic Session 1997 of the International Academy of the Philosophy of the Sciences cover the topic of philosophy of technology Half a dozen of other pertinent topical papers have been added in order to extend the topics dealt with and to reach a rather comprehensive overview of this multi ramified field Nowadays philosophy of technology is not only confronted with new anthropological and social as well as political problems to deal with but also with methodological problems of the mutual interactions between science and technology with problems of reliability and viability of technology assessment e g with risks environmental and social impact assessments The importance and necessity of a philosophy and a practice oriented ethics of technology will drastically rise and grow in the near future

Journal of the American Statistical Association American Statistical Association, 1992 *Analysis of the Electrical Activity of the Brain* Franco Angeleri, 1997-03-27 Ever since Galvani's discovery of the electrical sensitivity of the neuromuscular system in 1791 and the subsequent discovery that the EEG varied systematically with the functional state of the brain progress in neurophysiology and its clinical application has been dependent upon advances in technology With the

advent of computers however technology is no longer the rate limiting factor Computer programs are readily available to detect biologically significant signals amid background noise to characterise the EEG in terms of its spectral composition and dimensionality and even to calculate its anatomical generators from the topography of surface potentials and their derivatives Nowadays therefore problems tend to be encountered with the utility of the available mathematical algorithms and the ability of mathematicians and neurophysiologist to share their ideas Analysis of the Electrical Activity of the Brain aims to provide an accessible introduction to the use of mathematical concepts and algorithms in EEG data analysis and to promote an exchange of ideas between the disciplines of neurophysiology and applied mathematics Divided into sections covering nonlinear dynamical analysis spectral analysis signal detection and topography and source localisation the book includes details on all the latest techniques in addition to providing clear and understandable accounts of established methods Worked examples and case studies are featured to enable clinical neurophysiologists to increase their understanding of methods and to improve their knowledge of everyday techniques General and experimental neurophysiologists neurologists and physiologists together with applied mathematicians will also find this book to be of interest

Computational Mechanics of Cellular Automata James Edwin Hanson,1993

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