Benoit B. Mandelbrot

FRACTALS AND CHAOS

The Mandelbrot Set and Beyond

SELECTA VOLUME C

with a foreword by P.W. Jones and texts co-authored by C.J.G. Evertsz and M.C. Gutzwiller



Benoit B. Mandelbrot Mathematics Department Yale University New Haven, CT 06520-8283, USA http://www.math.yale.edu/mandelbrot and IBM T.J. Watson Research Center Yorktown Heights, NY 10598-0218, USA

ISBN 978-1-4419-1897-0 ISBN 978-1-4757-4017-2 (eBook) DOI 10.1007/978-1-4757-4017-2

Library of Congress Cataloging-in-Publication Data Mandelbrot, Benoit, B.

Fractals and chaos : the Mandelbrot set and beyond / Benoit Mandelbrot. p. cm.

Includes bibliographical references and index.

1. Fractals. 2. Mandelbrot sets. 2. Differentiable dynamical systems. I. Title. QA614.86.M23 2004 514'.742-dc22 2003063815

Printed on acid-free paper.

© 2004 Benoit B. Mandelbrot.

Originally published by Springer-Verlag New York, Inc. in 2004.

Softcover reprint of the hardcover 1st edition 2004

All rights reserved. This work may not be translated or copied in whole or in part without the written permission of the publisher Springer Science+Business Media, LLC except for brief excerpts in connection with reviews or scholarly analysis. Use in connection with any form of information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed is forbidden. The use in this publication of trade names, trademarks, service marks, and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

9 8 7 6 5 4 3 2 1 SPIN 10962329

springeronline.com

List of Chapters

In this List, * and (2003) mark the chapters not published previously. Other chapter titles are followed (in parentheses) by the letter M followed by the year of publication and by the lower case letter that the Bibliography uses to distinguish different texts published in the same year. In the Bibliography, the items reproduced in this book and in Volumes E, N and H are marked by a star followed by a chapter number, which in some cases is incomplete.

*Foreword by Peter W. Jones (2003)	 ix

*Preface (2003) 1

I QUADRATIC JULIA AND MANDELBROT SETS

*C1	Introduction to papers on quadratic dynamics: a progression from seeing to discovering (2003)
*C2	Acknowledgments related to quadratic dynamics (2003) 27
C3	Fractal aspects of the iteration of $z \rightarrow \lambda z$ (1- <i>z</i>) for complex λ and <i>z</i> (M1980n)
C4	Cantor and Fatou dusts ; self-squared dragons (M 1982F) 52
C5	The complex quadratic map and its M-set (M1983p) 73
C6	Bifurcation points and the " <i>n</i> squared" approximation and conjecture (M1985g), illustrated by M.L. Frame and K. Mitchell 96
C7	The "normalized radical" of the M-set (M1985g) 100
C8	The boundary of the M-set is of dimension 2 (M1985g) 110
C9	Certain Julia sets include smooth components (M1985g) 114
C10	Domain-filling sequences of Julia sets, and intuitive rationale for the Siegel discs (M1985g) 117
C11	Continuous interpolation of the quadratic map and intrinsic tiling of the interiors of Julia sets (M1985n)

II NONQUADRATIC RATIONAL DYNAMICS

*C12	Introduction to chaos in nonquadratic dynamics: rational functions devised from doubling formulas (2003)	137
C13	The map $z \rightarrow \lambda (z + 1/z)$ and roughening of chaos from linear to planar (computer-assisted homage to K. Hokusai) (M1984k)	146
C14	Two nonquadratic rational maps, devised from Weierstrass doubling formulas (1979-2003)	157
III	ITERATED NONLINEAR FUNCTION SYSTEMS AND THE FRACTAL LIMIT SETS OF KLEINIAN GROUPS	
*C15	Introduction to papers on Kleinian groups, their fractal limit sets, and IFS: history, recollections, and acknowledgments (2003)	171
C16	Self-inverse fractals, Apollonian nets, and soap (M 1982F)	178
C17	Symmetry by dilation or reduction, fractals, roughness (M2002w)	193
C18	Self-inverse fractals osculated by sigma-discs and limit sets of inversion ("Kleinian") groups (M1983m)	205
	and mine sets of inversion (Themanit's groups (MISSON)	200
IV	MULTIFRACTAL INVARIANT MEASURES	200
IV *C19	MULTIFRACTAL INVARIANT MEASURES Introduction to measures that vanish exponentially almost everywhere: DLA and Minkowski (2003)	200
IV *C19 C20	MULTIFRACTAL INVARIANT MEASURES Introduction to measures that vanish exponentially almost everywhere: DLA and Minkowski (2003) Invariant multifractal measures in chaotic Hamiltonian systems and related structures (Gutzwiller & M 1988)	221 231
IV *C19 C20 C21	MULTIFRACTAL INVARIANT MEASURES Introduction to measures that vanish exponentially almost everywhere: DLA and Minkowski (2003) Invariant multifractal measures in chaotic Hamiltonian systems and related structures (Gutzwiller & M 1988) The Minkowski measure and multifractal anomalies in invariant measures of parabolic dynamic systems (M1993s)	221 231 239
IV *C19 C20 C21 C22	MULTIFRACTAL INVARIANT MEASURES Introduction to measures that vanish exponentially almost everywhere: DLA and Minkowski (2003) Invariant multifractal measures in chaotic Hamiltonian systems and related structures (Gutzwiller & M 1988) The Minkowski measure and multifractal anomalies in invariant measures of parabolic dynamic systems (M1993s) Harmonic measure on DLA and extended self-similarity (M & Evertsz 1991)	221 231 239 251
 IV *C19 C20 C21 C22 V 	MULTIFRACTAL INVARIANT MEASURES Introduction to measures that vanish exponentially almost everywhere: DLA and Minkowski (2003) Invariant multifractal measures in chaotic Hamiltonian systems and related structures (Gutzwiller & M 1988) The Minkowski measure and multifractal anomalies in invariant measures of parabolic dynamic systems (M1993s) Harmonic measure on DLA and extended self-similarity (M & Evertsz 1991) BACKGROUND AND HISTORY	221 231 239 251
 IV *C19 C20 C21 C22 V *C23 	MULTIFRACTAL INVARIANT MEASURES Introduction to measures that vanish exponentially almost everywhere: DLA and Minkowski (2003) Invariant multifractal measures in chaotic Hamiltonian systems and related structures (Gutzwiller & M 1988) The Minkowski measure and multifractal anomalies in invariant measures of parabolic dynamic systems (M1993s) Harmonic measure on DLA and extended self-similarity (M & Evertsz 1991) BACKGROUND AND HISTORY The inexhaustible function z squared plus c (1982-2003)	221 231 239 251 259
 IV *C19 C20 C21 C22 V *C23 *C24 	MULTIFRACTAL INVARIANT MEASURES Introduction to measures that vanish exponentially almost everywhere: DLA and Minkowski (2003) Invariant multifractal measures in chaotic Hamiltonian systems and related structures (Gutzwiller & M 1988) The Minkowski measure and multifractal anomalies in invariant measures of parabolic dynamic systems (M1993s) Harmonic measure on DLA and extended self-similarity (M & Evertsz 1991) BACKGROUND AND HISTORY The inexhaustible function z squared plus c (1982-2003) The Fatou and Julia stories (2003)	221 231 239 251 259 268