Lecture Notes in Mathematics

Editors: A. Dold, Heidelberg F. Takens, Groningen

Springer Berlin

Berlin Heidelberg New York Barcelona Budapest Hong Kong London Milan Paris Santa Clara Singapore Tokyo Hiroaki Aikawa Matts Essén

Potential Theory – Selected Topics



Authors

Hiroaki Aikawwa Department of Mathematics Shimane University Matsue 690, Japan E-mail: haikawa@riko.shimane-u.ac.jp

Matts Essén Department of Mathematics Uppsala University Box 480 75106 Uppsala, Sweden E-mail: matts.essen@math.uu.se

Cataloging-in-Publication Data applied for

Die Deutsche Bibliothek - CIP-Einheitsaufnahme

Aikawa, Hiroaki:

Potential theory : selected topics / Hiroaki Aikawa ; Matts Essén. - Berlin ; Heidelberg ; New York ; Barcelona ; Budapest ; Hong Kong ; London ; Milan ; Paris ; Santa Clara ; Singapore ; Tokyo : Springer, 1996 (Lecture notes in mathematics ; 1633) ISBN 3-540-61583-0 NE: Essén, Matts:; GT

Mathematics Subject Classification (1991): 31B05, 31A05, 31B15, 31B25

ISSN 0075-8434 ISBN 3-540-61583-0 Springer-Verlag Berlin Heidelberg New York

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, re-use of illustrations, recitation, broadcasting, reproduction on microfilms or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1996 Printed in Germany

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typesetting: Camera-ready T_EX output by the authorsSPIN: 1047982946/3142-543210 - Printed on acid-free paper

During the academic years 1992–1994, there was a lot of activity on potential theory at the Department of Mathematics at Uppsala University. The main series of lectures were as follows:

- A An introduction to potential theory and a survey of minimal thinness and rarefiedness. (M. Essén)
- B Potential theory. (H. Aikawa)
- C Analytic capacity. (V. Eiderman)
- D Lectures on a paper of L.-I. Hedberg [24]. (M. Essén)
- E Harmonic measures on fractals (A. Volberg)

These lecture notes contain the lecture series A,B and references for C. The E lectures will appear as department report UUDM 1994:32: Zoltan Balogh, Irina Popovici and Alexander Volberg, Conformally maximal polynomial-like dynamics and invariant harmonic measure (to appear, Ergodic Theory and Dynamical Systems).

H. Aikawa spent the Spring semester 1993 in Uppsala. V. Eiderman spent the Spring semesters 1993 and 1994 here. A. Volberg was in Uppsala during May 1994. In addition to giving excellent series of lectures, our visitors were also very active participants in the mathematical life of the department.

Uppsala September 21, 1994

Matts Essén

Contents

art I by M. Essén	1
Preface	3
Introduction 2.1. Analytic sets 2.2. Capacity 2.3. Hausdorff measures 2.4. Is m_h a capacity?	4 4 5 9
The Physical background of Potential theory 3.1. Electrostatics in space	10 10
Potential theory 4.1. The maximum principle 4.2. α-potentials	11 13 16
Capacity 5.1. Equilibrium distributions 5.2. Three extremal problems 5.3. Every analytic set is capacitable	16 17 21 24
 Hausdorff measures and capacities 6.1. Coverings 6.2. Cantor sets 6.3. A Cantor type construction 	29 30 32 34
Two Extremal Problems 7.1. The Classical Case	36 38
M. Riesz kernels 8.1. Potentials 8.2. Properties of U_{α}^{λ} , where $\lambda = \lambda_F$. 8.3. The equilibrium measure 8.4. Properties of $C_{\alpha}(\cdot)$ 8.5. Potentials of measures in the whole space 8.6. The Green potential 8.7. Strong Subadditivity 8.8. Metric properties of capacity 8.9. The support of the equilibrium measures 8.10. Logarithmic capacity	39 40 45 46 47 49 53 54 57 57
	PrefaceIntroduction2.1. Analytic sets2.2. Capacity2.3. Hausdorff measures2.4. Is m_h a capacity?The Physical background of Potential theory3.1. Electrostatics in spacePotential theory4.1. The maximum principle4.2. α -potentialsCapacity5.1. Equilibrium distributions5.2. Three extremal problems5.3. Every analytic set is capacitableHausdorff measures and capacities6.1. Coverings6.2. Cantor sets6.3. A Cantor type constructionTwo Extremal Problems7.1. The Classical CaseM. Riesz kernels8.1. Potentials8.2. Properties of U^{λ}_{α} , where $\lambda = \lambda_F$.8.3. The equilibrium measure8.4. Properties of $C_{\alpha}(\cdot)$ 8.5. Potentials of measures in the whole space8.6. The Green potential8.7. Strong Subadditivity8.8. Metric properties of capacity8.9. The support of the equilibrium measures

8.11. Polar sets 8.12. A classical connection	60 61
8.12. A classical connection 8.13. Another definition of capacity	61
9. Reduced functions	61
10. Green energy in a Half-space	65
10.1. Properties of the Green energy γ	66 67
10.2. Ordinary thinness	
11. Minimal thinness 11.1. Minimal thinness, Green potentials and Poisson integrals	68 68
11.2. A criterion of Wiener type for minimal thinness	71
12. Rarefiedness	73
13. A criterion of Wiener type for rarefiedness	74
14. Singular integrals and potential theory	75
15. Minimal thinness, rarefiedness and ordinary capacity	81
16. Quasiadditivity of capacity	88
17. On an estimate of Carleson	90
1. Books on potential theory: a short list	93
1.1. Classical potential theory	93
1.2. Potential theory and function theory in the plane	93
1.3. Abstract potential theory	93 93
 1.4. Nonlinear potential theory 1.5. Potential theory and probability 	93
1.6. Pluripotential theory	90 94
Bibliography	95
Index	97
Analytic capacity (references) by V. Eiderman	99
Part II by H. Aikawa	101
1. Introduction	103
2. Semicontinuous functions	105
2.1. Definition and elementary properties	105
2.2. Regularizations	106
2.3. Approximation	106
2.4. Vague convergence	107
3. L^p capacity theory	108
3.1. Preliminaries	108
3.2. Definition and elementary properties	109
3.3. Convergence properties	110
3.4. Capacitary distributions	112
3.5. Dual capacity	$114 \\ 115$
3.6. Duality 3.7. Relationship between capacitary distributions	113
3.8. Capacitary measures and capacitary potentials	110
sist supervery measures and capacitally possible	100

CONTENTS

2	Capacity of balls 4.1. Introduction 4.2. Preliminaries 4.3. Kerman-Sawyer inequality 4.4. Capacity of balls 4.5. Metric Property of Capacity	122 122 124 126 129 130
Į	Capacity under a Lipschitz mapping 5.1. Introduction 5.2. Proof of Theorem 5.1.1 5.3. Proof of Theorem 5.1.2	1 32 132 133 136
6	Capacity strong type inequality 6.1. Weak maximum principle 6.2. Capacity strong type inequality 6.3. Lemmas 6.4. Proof of Theorem 6.2.1	137 137 140 140 142
ء ب	Quasiadditivity of capacity 7.1. Introduction 7.2. How do we get a comparable measure? 7.3. Green energy 7.4. Application	144 144 149 152 155
8 8 8 8	 Fine limit approach to the Nagel-Stein boundary limit theorem 8.1. Introduction 8.2. Boundary behavior of singular harmonic functions 8.3. Proof of Theorem 8.1.1 8.4. Sharpness of Theorem 8.1.1 and Theorem 8.2.1 8.5. Necessity of an approach region 8.6. Further results 	158 158 162 165 167 169 170
	 Integrability of superharmonic functions 9.1. Integrability for smooth domains 9.2. Integrability for Lipschitz domains 9.3. Integrability for nasty domains 9.4. Sharp integrability for plane domains 9.5. Sharp integrability for Lipschitz domains 9.6. Lower estimate of the gradient of the Green function 	171 171 172 174 175 175 180
	Appendix: Choquet's capacitability theorem 10.1. Analytic sets are capacitable 10.2. Borel sets are analytic	182 182 183
-	Appendix: Minimal fine limit theorem11.1. Introduction11.2. Balayage (Reduced function)11.3. Minimal thinness11.4. PWB ^h solution11.5. Minimal fine boundary limit theorem	184 184 185 187 190 193
	bliography	195
Ind	ex	198

ix