

J. Richard Büchi

Finite Automata, Their Algebras and Grammars

Towards a Theory of Formal Expressions

Dirk Siefkes
Editor

With 88 Illustrations



Springer Science
+Business Media, LLC

J. Richard Büchi
Computer Science Department
Purdue University
West Lafayette, Indiana 47907
U.S.A.

Dirk Siefkes, editor
Technische Universität Berlin
Fachbereich Informatik
D-1000 Berlin
Federal Republic of Germany

Library of Congress Cataloging-in-Publication Data

Büchi, J. Richard.

Finite automata, their algebras and grammars: towards a theory of
formal expressions / J. Richard Büchi; Dirk Siefkes, editor.

p. cm.

Bibliography: p.

Includes indexes.

ISBN-13: 978-1-4613-8855-5

1. Sequential machine theory. I. Siefkes, Dirk. II. Title.

QA267.5.S4B83 1988

511—dc 19

88-37420

Printed on acid-free paper

© 1989 by Springer Science+Business Media New York
Originally published by Springer-Verlag New York Inc. in 1989
Softcover reprint of the hardcover 1st edition 1989

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 of general descriptive names, trade names, trademarks, etc. in this publication, even if the former are not especially identified, is not to be taken as a sign that such names, as understood by the Trade Marks and Merchandise Marks Act, may accordingly be used freely by anyone.

Typeset by Asco Trade Typesetting Ltd., Hong Kong.

9 8 7 6 5 4 3 2 1

ISBN 978-1-4613-8855-5 ISBN 978-1-4613-8853-1 (eBook)
DOI 10.1007/978-1-4613-8853-1

Contents

Preface of the Editor	v
Introduction	xv
Chapter 1	
Concepts and Notations in Discrete Mathematics	1
§1.1. The Notations of Logic	1
§1.2. The Natural Number System	8
§1.3. Sets and Functions	13
§1.4. Binary Relations, Isomorphisms	26
§1.5. Equivalence Relations, Partial Orders, and Rectangular Relations	30
§1.6. Lattices and Boolean Algebras	39
§1.7. Set Lattices and Quasi-Orders	47
§1.8. Semi-set Lattices and Closure Spaces	58
§1.9. Discrete Closure Spaces	63
§1.10. Classification of Closure Spaces	66
§1.11. Procedures of Computation, Production, and Proof	70
Chapter 2	
The Structure Theory of Transition Algebras	76
§2.1. The Transition Algebra of a Logical Net	77
§2.2. The Response Function of a k -Algebra	81
§2.3. Accessible States of a Transition Algebra	84
§2.4. The Basic Concepts of Algebra and Their Meaning for Automata	88
§2.5. The Structure Lattice of k -Algebras	99

Chapter 3

The Structure and Behavior of Finite Automata	106
§3.1. The Outputs of a k -Algebra	106
§3.2. The Minimal Automaton of Given Behavior	115
§3.3. Finite-State Acceptors and Their Right- and Left-Behaviors	117
§3.4. Periodic Sets of Words	126

Chapter 4

Transition Systems and Regular Events	133
§4.1. Transition Systems and the Subset Construction	134
§4.2. The Behavior of Transition Systems with Output	140
§4.3. Spontaneous Transitions, Closure Properties on Periodic Events	144
§4.4. Regular Events	149
§4.5. Regular Expressions; the Analysis and Synthesis Theorems	151
§4.6. Starheight and Feedback Number	156
§4.7. General Transition Systems, the Coding Lemmas	165
§4.8. Systems Are Quotients of Algebras, Modulo-Compatible Closure Relations	169

Chapter 5

Regular Canonical Systems	180
§5.1. Regular Systems and Finite Automata	181
§5.2. Finite Automata Are Regular Systems	187
§5.3. Minimal and Periodic Descriptions of a Regular Set	190
§5.4. Regular Systems Produce Periodic Sets	197
§5.5. Regular Rules with Many Premises	200
§5.6. Right and Left Regular Rules	207
§5.7. Normal Systems and Regular Systems	212

Chapter 6

General Algebras: How They Function as Tree Acceptors and Push-down Automata	217
§6.1. How Terms Are Constructed from the Outside and from the Inside	220
§6.2. Terms Are Trees and Trees Are Terms; The Run of a Production	231
§6.3. Algebras, and How They Respond to Input Signals	236
§6.4. Standard Presentation of Algebras	243
§6.5. The Behavior of Finite Tree Acceptors, Periodic Sets of Terms	245
§6.6. Regular Sets of Terms; Analysis and Synthesis of Finite Tree Acceptors	247
§6.7. How I-Automata Accept Terms in Tree Time and in Real Time; Tree Automata and Push-down Automata	251
§6.8. Regular Tree-producing Grammars	262

Chapter 7

General Alphabets: The Theory of Push-down Automata and Context-free Languages	271
§7.1. General Alphabets, and How They Produce Terms from the Outside and from the Inside	274
§7.2. Leibniz–Thue law, and the Basic Grammatical Facts about Terms ..	278
§7.3. Push-down Automata and Context-free Languages	282
§7.4. Push-down Parsers for LR_k -Grammars	285
Conclusion	292
List of Symbols	293
References	299
Index	305