Computer Science and Applied Mathematics

PICTURE LANGUAGES

FORMAL MODELS FOR PICTURE RECOGNITION

Azriel Rosenfeld

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Formal Models for Picture Recognition

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ACADEMIC PRESS New York San Francisco London 1979

A Subsidiary of Harcourt Brace Jovanovich, Publishers

ACADEMIC PRESS, INC.
111 Fifth Avenue, New York, New York 10003

United Kingdom Edition published by
ACADEMIC PRESS, INC. (LONDON) LTD.
24/28 Oval Road, London NW1 7DX

Library of Congress Cataloging in Publication Data

Rosenfeld, Azriel, Date
Picture languages.

(Computer science and applied mathematics)
Includes bibliographical references and index.
1. Machine theory. 2. Optical Pattern recognition.
3. Formal languages. I. Title.
QA267.R67 629.8'91 78-11256
ISBN 0-12-597340-3

PRINTED IN THE UNITED STATES OF AMERICA

79 80 81 82 83 84 85 9 8 7 6 5 4 3 2 1

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To my father

ACKNOWLEDGMENTS

The material in this book is based on the work of a number of authors; see the bibliographies at the ends of the chapters for specific attributions. In particular, Chapter 6, on cellular pyramids, is largely the work of C. R. Dyer.

The helpful comments of C. R. Dyer and D. L. Milgram, among others, on a draft of the book are greatly appreciated, as is the typing support that was ably provided by Shelly Rowe. Finally, the support received by the author from the Directorate of Mathematical and Information Sciences, U.S. Air Force Office of Scientific Research, is gratefully acknowledged.

AUTOMATON NOMENCLATURE

For the sake of compactness, abbreviations have usually been used for the names of the various types of automata and languages discussed in this book. The following is a summary of the notation used to construct these abbreviations.

TYPES OF AUTOMATA OR LANGUAGES

BC	bounded cellular
C	cellular
PC	pyramid cellular
TC	triangle cellular
PS	parallel/sequential
NWPS	nonwriting parallel/sequential
FS	finite-state
PD	pushdown
#P	#-preserving
TB	tape-bounded
T	Turing

SPECIAL TYPES

DLP	diameter-limited perceptron
FRA	frontier-to-root tree acceptor

SUFFIXES

A	acceptor
L	language
M	machine

PREFIXES

		USED WITH
D	deterministic	all
N	nondeterministic	all
OW	one-way	FS,PD(#P,TB,T)
TW	three-way	FS
U	bottom–up	PC,TC

EXAMPLES

NTBL	nondeterministic tape-bounded language
DOWFSA	deterministic one-way finite-state acceptor
UTCA	bottom–up triangle cellular acceptor

CONTENTS

Chapter 8
Grammars

Chapter 1

INTRODUCTION

This book has two potential classes of readers. For those interested in pattern recognition, it introduces a class of formal approaches; for those interested in automata theory, it presents some basic results on two-dimensional languages. The first two sections of this introduction are addressed to these two groups of readers.

1.1 FOREWORD ON PICTURE RECOGNITION

Pictorial pattern recognition is a well-established and active field [1–3], with numerous applications in such areas as document processing (character recognition), industrial automation (assembly, inspection), medicine (cytology, radiology), and remote sensing, among many others. Efficient picture recognition systems are thus a matter of great practical interest. However, relatively little is known about the computational theory of picture recognition. Given a class of digital pictures (i.e., arrays of numbers representing gray levels), and a class of allowable operations on pictures, one would like to be able to answer such questions as:

(a) What types of recognition tasks are feasible? For what properties is it possible to determine whether or not a given picture has the given property?
(b) What is the minimum number of operations (of the given type) required to perform a given recognition task (for pictures of a given size)?

(c) How can the minimum required computation time be reduced by allowing sets of operations to be performed in parallel?

This book treats these questions from the rather formal standpoint of automata theory. *Array automata* are simple processors that perform sequences of operations on arrays (e.g., pictures); their recognition power depends on which operations they are allowed to perform. *Cellular array automata* are arrays of processors that operate on pictures in a highly parallel fashion (one processor per picture element). The capabilities and relative efficiencies of various types of these automata with respect to various array recognition tasks are the main subject of this book.

Cellular arrays have been frequently proposed, and in a few cases, actually implemented, as fast picture-processing machines (e.g., [4–6]). The growing availability of integrated circuits makes their realization in hardware increasingly practical. Thus the material in this book on cellular recognition algorithms (Chapters 5 and 6, in particular) is of potential practical interest to designers and users of such hardware.

It must be admitted that automata are rather artificial models for picture processing and recognition. As ordinarily defined, an automaton has a bounded amount of internal memory (the condition of which, at a given time, is called the automaton's "state"), and this amount is the same no matter what the size of the input picture array. Thus an automaton cannot internally perform arithmetic operations on numbers of arbitrary size. It cannot even address an arbitrary element of the array, since specifying the coordinates of that element requires a number of bits that does grow (logarithmically) with the array size. Instead, it moves around on the array by making sequences of moves of bounded size—typically, from a given picture element to one of its neighbors. Similarly, the automata in a cellular array are each allowed only a bounded amount of internal memory; thus they cannot address arbitrarily specified cells in the array, but rather pass information from neighbor to neighbor.

In spite of (or perhaps because of) these restrictions, automaton models for picture recognition have been extensively studied, and many theoretical results about their capabilities have been established. This book provides a systematic introduction to this work.

Some work has also been done on other formal recognition models; a notable example is the monograph by Minsky and Papert on "Perceptrons" [7], in which linear threshold functions are used for picture property recognition (see Section 6.3.3). However, further work is needed on models that are less artificial. It is hoped that progress will be made in this direction during the coming years.

1.2 FOREWORD ON AUTOMATA THEORY

This book presents a collection of results on two-dimensional sequential and parallel (cellular) array acceptors (Chapters 4–7). For convenience, some of the analogous one-dimensional results are also reviewed (Chapter 3). Array grammars and their relation to acceptors are also treated (Chapter 8).

Array acceptors have been much less extensively studied than string acceptors, and are usually not treated in any detail in courses on automata and formal languages. However, they have a number of features that should make them of interest to automata theorists. Many of the standard one-dimensional results, e.g., the equivalence of nondeterministic and deterministic finite-state acceptors, break down in two dimensions. Certain array properties, such as connectedness, are trivially recognizable in one dimension, but are much less tractable in two. Array grammars must be defined in a special ("isometric") way in order to ensure that the application of rewriting rules does not have nonlocal effects on the array topology. In addition, many simple questions about array languages remain open. These and many other factors make the study of two-dimensional languages of special interest (aside from their relevance to picture recognition, as suggested in Section 1.1). It is hoped that this book will help to encourage their further study by automata theorists.

1.3 SCOPE OF THIS BOOK

Chapter 2 reviews a number of topics in *digital geometry*—the theory of geometrical properties of subsets of digital pictures. The subjects covered include connectedness, surroundedness, arcs and curves, borders, perimeter, distance, diameter, and geodesics. This theory provides the foundations for a number of basic array automaton algorithms (e.g., border following, region traversal) that are developed in later chapters. From a more practical standpoint, it serves as a basis for defining and proving the correctness of various fundamental image analysis operations, such as object counting (i.e., connected component counting) and chain encoding [8] of region borders.

Chapter 3 reviews one-dimensional (string) automata and cellular automata, with emphasis on results whose two-dimensional analogs are treated in the subsequent chapters. Chapter 4 treats (sequential) array automata, and Chapter 5 deals with cellular array automata. Chapters 6 and 7 discuss a number of special automaton models, including "cellular pyramids," pebble and pushdown automata, and parallel/sequential array automata. Chapter 8 is concerned with array grammars (including a brief review of string grammars), both sequential and parallel, and with their relationship to array automata. (Many other "grammar" models for picture languages have been proposed, and considerable work has been done on the use of syntactic methods in pattern recognition; see [9] for a review of this subject.)

The content of this book is basically mathematical, but an informal approach has been taken, especially in the proofs. Understandability has been favored over formal precision. To promote intelligibility, the most efficient algorithms possible have not always been given. It is hoped that the presentation will be found readable even by those having little or no previous exposure to automata theory.

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