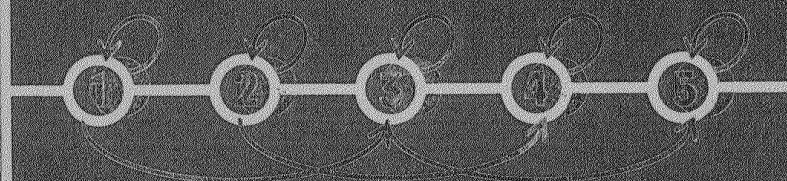


DISCRETE-TIME PROCESSING OF SPEECH SIGNALS



JOHN R. DELLER, JR.
JOHN G. PROAKIS
JOHN H. L. HANSEN

Michelle Coull

Discrete-Time Processing of Speech Signals

John R. Deller, Jr. *Michigan State University*

John G. Proakis *Northeastern University*

John H. L. Hansen *Duke University*

Macmillan Publishing Company
New York

Maxwell Macmillan Canada
Toronto

Maxwell Macmillan International
New York Oxford Singapore Sydney

Editor: John Griffin
Production Supervisor: Elaine W. Wetterau
Production Manager: Roger Vergnes
Text Designer: Natasha Sylvester
Cover Designer: Cathleen Norz
Illustrations: Academy ArtWorks, Inc.

This book was set in Times Roman by Graphic Sciences Corporation,
printed and bound by Book Press.

Copyright © 1993 by Macmillan Publishing Company, a division of Macmillan, Inc.

Printed in the United States of America

All rights reserved. No part of this book may be reproduced or
transmitted in any form or by any means, electronic or mechanical,
including photocopying, recording, or any information storage and
retrieval system, without permission in writing from the publisher.

Macmillan Publishing Company
113 Sylvan Avenue, Englewood Cliffs, NJ 07632

Library of Congress Cataloging in Publication Data

Deller, John R.
Discrete-time processing of speech signals / John R. Deller, John
G. Proakis, John H. L. Hansen.
p. cm.
Includes index.
ISBN 0-02-328301-7
1. Speech processing systems. 2. Signal processing—Digital
techniques. 3. Discrete-time systems. I. Proakis, John G.
II. Hansen, John H. L. III. Title.
TK7882.S65D44 1993
621.382'2—dc20

92-38644
CIP

Printing: 2 3 4 5 6 7 8 Year: 5 6 7 8 9 0 1 2

Propaedeutic

Read.Me: If you are someone who never reads Chapter 1, please at least read Sections 1.0.2 and 1.0.3 before proceeding!

1.0 Preamble

1.0.1 The Purpose of Chapter 1

If the reader learns nothing more from this book, it is a safe bet that he or she will learn a new word. A *propaedeutic*¹ is a “preliminary body of knowledge and rules necessary for the study of some art or science” (Barnhart, 1964). This chapter is just that—a propaedeutic for the study of speech processing focusing primarily on two broad areas, digital signal processing (DSP) and stochastic processes, and also on some necessary topics from the fields of statistical pattern recognition and information theory.

The reader of this book is assumed to have a sound background in the first two of these areas, typical of an entry level graduate course in each field. It is not our purpose to comprehensively teach DSP and random processes, and the brief presentation here is not intended to provide an adequate background. There are many fine textbooks to which the reader might refer to review and reinforce prerequisite topics for these subjects. We list a considerable number of widely used books in Appendices 1.A and 1.B.

What, then, is the point of our propaedeutic? The remainder of this chapter is divided into four main sections plus one small section, and the tutorial goals are somewhat different in each. Let us first consider the two main sections on DSP and stochastic processes. In the authors’ experience, the speech processing student is somewhat more comfortable with “deterministic” DSP topics than with random processes. What we will do in Section 1.1, which focuses on DSP, therefore, is highlight some of the key concepts which will play central roles in our speech processing work. Where the material seems unfamiliar, the reader is urged to seek help in

¹Pronounced “prō’-pa-doo’-tic.”

one or more of the DSP textbooks cited in Appendix 1.A. Our main objective is to briefly outline the essential DSP topics with a particular interest defining notation that will be used consistently throughout the book. A second objective is to cover a few subtler concepts that will be important in this book, and that might have been missed in the reader's first exposure to DSP.

The goals of Section 1.2 on random processes are somewhat different. We will introduce some fundamental concepts with a bit more formality, uniformity, and detail than the DSP material. This treatment might at first seem unnecessarily detailed for a textbook on speech processing. We do so, however, for several reasons. First, a clear understanding of stochastic process concepts, which are so essential in speech processing, depends strongly on an understanding of the basic probability formalisms. Second, many engineering courses rely heavily on stochastic processes and not so much on the underlying probability concepts, so that the probability concepts become "rusty." Emerging technologies in speech processing depend on the basic probability theory and some review of these ideas could prove useful. Third, it is true that the mastery of any subject requires several "passes" through the material, but engineers often find this especially true of the field of probability and random processes.

The third and fourth major divisions of this chapter, Sections 1.3 and 1.4, treat a few topics which are used in the vast fields of statistical pattern recognition and information theory. In fact, we have included some topics in Section 1.3 which are perhaps more general than "pattern recognition" methods, but the rubric will suffice. These sections are concerned with basic mathematical tools which will be used frequently, and in diverse ways in our study, beginning in Part IV of the book. There is no assumption that the reader has formal coursework in these topics beyond the normal acquaintance with them that would ordinarily be derived from an engineering education. Therefore, the goal of these sections is to give an adequate description of a few important topics which will be critical to our speech work.

Finally, Section 1.5 briefly reviews the essence and notation of phasors and steady-state analysis of systems described by differential equations. A firm grasp of this material will be necessary in our early work on analog acoustic modeling of the speech production system in Chapter 3.

As indicated above, the need for the subjects in Sections 1.3–1.5 is not immediate, so the reader might wish to scan over these sections, then return to them as needed. More guidance on reading strategy follows.

1.0.2 Please Read This Note on Notation

The principal tool of engineering is applied mathematics. The language of mathematics is abstract symbolism. This book is written with a conviction that careful and consistent notation is a sign of clear under-

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.