
Editor: Manfred R. Schroeder



Springer Series in Information Sciences

Editors: Thomas S. Huang Teuvo Kohonen Manfred R. Schroeder
Managing Editor: H.K.V. Lotsch

- 1 **Content-Addressable Memories**
By T. Kohonen 2nd Edition
 - 2 **Fast Fourier Transform and Convolution Algorithms**
By H. J. Nussbaumer 2nd Edition
 - 3 **Pitch Determination of Speech Signals**
Algorithms and Devices By W. Hess
 - 4 **Pattern Analysis** By H. Niemann
2nd Edition
 - 5 **Image Sequence Analysis**
Editor: T.S. Huang
 - 6 **Picture Engineering**
Editors: King-sun Fu and T.L. Kunii
 - 7 **Number Theory in Science and Communication** With Applications in
Cryptography, Physics, Digital
Information, Computing, and Self-
Similarity By M.R. Schroeder
2nd Edition
 - 8 **Self-Organization and Associative
Memory** By T. Kohonen 3rd Edition
 - 9 **Digital Picture Processing**
An Introduction By L.P. Yaroslavsky
 - 10 **Probability, Statistical Optics and
Data Testing** A Problem Solving
Approach By B.R. Frieden
 - 11 **Physical and Biological Processing of
Images** Editors: O.J. Braddick and
A.C. Sleight
 - 12 **Multiresolution Image Processing and
Analysis** Editor: A. Rosenfeld
 - 13 **VLSI for Pattern Recognition and
Image Processing** Editor: King-sun Fu
 - 14 **Mathematics of Kalman-Bucy Filtering**
By P.A. Ruymgaart and T.T. Soong
2nd Edition
 - 15 **Fundamentals of Electronic Imaging
Systems** Some Aspects of Image
Processing By W.F. Schreiber
 - 16 **Radon and Projection Transform-
Based Computer Vision**
Algorithms, A Pipeline Architecture, and
Industrial Applications By J.L.C. Sanz,
E.B. Hinkle, and A.K. Jain
 - 17 **Kalman Filtering with Real-Time
Applications** By C.K. Chui and G. Chen
 - 18 **Linear Systems and Optimal Control**
By C.K. Chui and G. Chen
 - 19 **Harmony: A Psychoacoustical
Approach** By R. Parncutt
 - 20 **Group Theoretical Methods in Image
Understanding** By Ken-ichi Kanatani
 - 21 **Linear Prediction Theory**
A Mathematical Basis for Adaptive
Systems By P. Strobach
-

Richard Parncutt

Harmony: A Psychoacoustical Approach

With 22 Figures

Springer-Verlag Berlin Heidelberg New York
London Paris Tokyo Hong Kong

Dr. Richard Parncutt

Departments of Music and Psychology,
University of New England, Armidale NSW 2351, Australia

Series Editors:

Professor Thomas S. Huang

Department of Electrical Engineering and Coordinated Science Laboratory,
University of Illinois, Urbana, IL 61801, USA

Professor Teuvo Kohonen

Department of Technical Physics, Helsinki University of Technology,
SF-02150 Espoo 15, Finland

Professor Dr. Manfred R. Schroeder

Drittes Physikalisches Institut, Universität Göttingen, Bürgerstrasse 42–44,
D-3400 Göttingen, Fed. Rep. of Germany

Managing Editor: **Helmut K. V. Lotsch**

Springer-Verlag, Tiergartenstrasse 17,
D-6900 Heidelberg, Fed. Rep. of Germany

ISBN-13 : 978-3-642-74833-2 e-ISBN-13 : 978-3-642-74831-8

DOI: 10.1007/978-3-642-74831-8

Library of Congress Cataloging-in-Publication Data. Parncutt, Richard. 1957–. Harmony: a psychoacoustical approach / Richard Parncutt. p. cm. – (Springer series in information sciences: 19) Bibliography: p. Includes index. 1. Music – Psychology. 2. Harmony. 3. Music – Acoustics and physics. I. Title. II. Series. ML3836.P3 1989 781.2'5'019–dc19 89-11555

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, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in other ways, and storage in data banks. Duplication of this publication or parts thereof is only permitted under the provisions of the German Copyright Law of September 9, 1965, in its version of June 24, 1985, and a copyright fee must always be paid. Violations fall under the prosecution act of the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1989
Softcover reprint of the hardcover 1st edition 1989

The use of 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: K & V Fotosatz, 6124 Beerfelden
2154/3150-543210 – Printed on acid-free paper

To the pacifists

Preface

My first encounter with the theory of harmony was during my last year at school (1975). This fascinating system of rules crystallized the intuitive knowledge of harmony I had acquired from years of piano playing, and facilitated memorization, transcription, arrangement and composition. For the next five years, I studied music (piano) and science (physics) at the University of Melbourne. This “strange combination” started me wondering about the *origins* of those music theory “rules”. To what extent were they determined or influenced by physics? mathematics? physiology? conditioning?

In 1981, the supervisor of my honours project in musical acoustics, Neville Fletcher, showed me an article entitled “Pitch, consonance, and harmony”, by a certain Ernst Terhardt of the Technical University of Munich. By that stage, I had devoured a considerable amount of (largely unsatisfactory) material on the nature and origins of harmony, which enabled me to recognize the significance of Terhardt’s article. But it was not until I arrived in Munich the following year (on Terhardt’s invitation) that I began to appreciate the consequences of his “psychoacoustical” approach for the theory of harmony. That is what this book is about.

The book presents Terhardt’s work against the broad context of music perception research, past and present. Music perception is a multidisciplinary mixture of physics, psychology and music. Where different theoretical approaches appear contradictory, I try to show instead that they complement and enrich one another. Readers are assumed to be acquainted with basic principles of harmony, acoustics (including spectral analysis), and computer modelling.

The book is based on my Ph.D. thesis, which was submitted in 1986 at the University of New England, Armidale NSW, Australia. I am indebted to my supervisors, Neville Fletcher (Physics), Catherine Ellis (Music) and William Noble (Psychology), for their active interest, informed criticism and general guidance; to Gerhard Stoll and David Heap, for helping to set up the experiments; to my Ph.D. examiners, Howard Pollard (Physics, University of New South Wales), Alan Costall (Psychology, University of Southampton) and Jeff Pressing (Music, La Trobe University), for helpful suggestions, criticism and encouragement; and to Neil Buckland, for music-oriented comments.

The theoretical content of the book was influenced and inspired by conversations with staff of the Institute of Electroacoustics, TU Munich, and with academics and students met at conferences and visited during and after my Ph.D. Special thanks to Juan Roederer for organizing the Workshops on the

Physics and Neuropsychology of Music at Ossiach, Austria, which I attended in 1983 and 1985.

Most of all I would like to thank Ernst Terhardt, for his hospitality, approachability and critical guidance during my stay in Munich in 1982–1983. I hope with this book to bring his work to the attention of a wider public, and thereby to contribute to the demystification of the harmonic conventions of Western music.

Armidale, May 1988

Richard Parncutt

Contents

1. Background	1
1.1 Music Theory	1
1.1.1 Introduction	1
1.1.2 Single Chords	2
1.1.3 Pairs of Chords	4
1.1.4 Chord Progressions	5
1.1.5 A Scientific Basis?	5
1.2 Physically Based Theories	6
1.2.1 Introduction	6
1.2.2 Frequency Ratios	7
1.2.3 Harmonic Series	8
1.2.4 Beats	9
1.2.5 Combination Tones	10
1.2.6 Periodicity	10
1.3 Psychologically Based Theories	11
1.3.1 Introduction	11
1.3.2 Cognitive Structures	12
1.3.3 Generative Grammars	13
1.3.4 Mathematical Groups	15
1.4 Towards a Psychophysical Theory	16
1.4.1 From Rameau to Terhardt	16
1.4.2 The Psychoacoustical Approach	17
1.4.3 Outline of the Book	18
2. Psychoacoustics	19
2.1 Philosophy of Perception	19
2.1.1 Hardware and Software	19
2.1.2 Matter, Experience and Information	20
2.1.3 Perception, Sensation and Cognition	22
2.1.4 Tone, Tone Sensation and Note	23
2.2 Auditory Sensation	24
2.2.1 Loudness and Timbre	24
2.2.2 Spectral Analysis	26
2.2.3 Sensory Memory	28
2.3 Extraction of Information	29
2.3.1 Noticing and Salience	29

2.3.2	Categorical Perception	29
2.3.3	Holistic Perception and Pattern Recognition	30
2.3.4	Ambiguity, Multiplicity and Context	32
2.4	Tone Sensation	33
2.4.1	Terminology	33
2.4.2	Pure Tone Sensations	34
2.4.3	Complex Tone Sensations	35
2.4.4	Pitch Ambiguity of Complex Tones	38
2.4.5	Subharmonic Pitches of Pure Tones	39
2.4.6	Melodic Streaming	40
2.5	Pitch Perception	42
2.5.1	Dimensionality	42
2.5.2	Continuous Pitch Scales	43
2.5.3	Categorical Pitch Perception	44
2.5.4	Musical Training	45
2.5.5	Perfect Pitch	46
3.	Psychomusicology	48
3.1	Conditioning	48
3.1.1	Sensory Versus Cultural	48
3.1.2	Prenatal Conditioning	50
3.2	Consonance	56
3.2.1	Introduction	56
3.2.2	Roughness and Tonalness	58
3.2.3	Pitch Commonality and Pitch Distance	60
3.3	Musical Pitch	61
3.3.1	Octave Equivalence	61
3.3.2	The Chromatic Scale	62
3.3.3	Intonation	65
3.4	Tonality	68
3.4.1	Introduction	68
3.4.2	The Root of a Chord	68
3.4.3	The Tonic of a Scale	70
3.4.4	Major/Minor and Emotion	73
3.4.5	Chord Progressions	75
4.	Model	77
4.1	General Aspects	77
4.1.1	Aim, Form and Implementation	77
4.1.2	Formulation and Assessment	78
4.1.3	Culture-Specific Aspects	79
4.1.4	Comparison with Terhardt's Model	80
4.2	Input	81
4.2.1	Pitch Category	81
4.2.2	Experiments	81

4.2.3 Auditory Level	82
4.2.4 Applications	83
4.3 Masking and Audibility	85
4.3.1 Critical Bandwidth	85
4.3.2 Masking	87
4.3.3 Audibility	88
4.4 Recognition of Harmonic Pitch Patterns	89
4.4.1 Harmonic Template	89
4.4.2 Complex Tone Sensations	89
4.4.3 Tonalness	91
4.5 Saliency	92
4.5.1 Multiplicity	92
4.5.2 Tone Saliency	93
4.5.3 Chroma Saliency	94
4.6 Sequential Pitch Relationship	94
4.6.1 Pitch Commonality	94
4.6.2 Pitch Distance	95
4.6.3 Pitch Analysis Experiment	96
4.6.4 Similarity Experiments	97
5. Experiments	98
5.1 General Method	98
5.1.1 Results and Modelling	98
5.1.2 Cultural Effects	99
5.2 Multiplicity	100
5.2.1 Introduction	100
5.2.2 Method	101
5.2.3 Results	103
5.2.4 Modelling	103
5.2.5 Conclusions	105
5.3 Pitch Analysis	105
5.3.1 Introduction	105
5.3.2 Method	107
5.3.3 Results	110
5.3.4 Modelling	111
5.3.5 Conclusions	112
5.4 Similarity of Piano Tones	113
5.4.1 Introduction	113
5.4.2 Method	113
5.4.3 Results	114
5.4.4 Grouping	116
5.4.5 Conclusions	116
5.5 Similarity of Synthetic Tones I	117
5.5.1 Introduction	117
5.5.2 Method	117

5.5.3 Results	118
5.5.4 Grouping	121
5.5.5 Conclusions	121
5.6 Similarity of Synthetic Tones II	122
5.6.1 Introduction	122
5.6.2 Method	123
5.6.3 Grouping and Results	124
5.6.4 Modelling	128
5.6.5 Conclusions	129
5.7 Similarity of Chords	129
5.7.1 Introduction	129
5.7.2 Method	130
5.7.3 Results	130
5.7.4 Modelling	131
5.7.5 Conclusions	132
5.8 Discussion	132
5.8.1 Modelling	132
5.8.2 Musical Universals?	133
6. Applications	135
6.1 Simultaneities	135
6.1.1 Masking	135
6.1.2 Spectral Dominance	137
6.1.3 Multiplicity	138
6.1.4 Tonalness	139
6.1.5 Pitch Analyses	142
6.1.6 Chroma Salience and the Root	146
6.2 Progression	150
6.2.1 Pitch Commonality	150
6.2.2 Pitch Distance	154
6.2.3 Tonicity	155
6.2.4 Implied Triad/Scale	157
6.2.5 Key Profile	158
6.3 Pieces	162
6.3.1 Analysis	162
6.3.2 Composition	165
Glossary	167
Glossary of Symbols	182
References	185
Subject Index	201