

Human–Computer Interaction Series

Editors-in-Chief

Desney Tan

Microsoft Research, Redmond, WA, USA

Jean Vanderdonckt

Louvain School of Management, Université catholique de Louvain,
Louvain-La-Neuve, Belgium

The Human–Computer Interaction Series, launched in 2004, publishes books that advance the science and technology of developing systems which are effective and satisfying for people in a wide variety of contexts. Titles focus on theoretical perspectives (such as formal approaches drawn from a variety of behavioural sciences), practical approaches (such as techniques for effectively integrating user needs in system development), and social issues (such as the determinants of utility, usability and acceptability).

HCI is a multidisciplinary field and focuses on the human aspects in the development of computer technology. As technology becomes increasingly more pervasive the need to take a human-centred approach in the design and development of computer-based systems becomes ever more important.

Titles published within the Human–Computer Interaction Series are included in Thomson Reuters' Book Citation Index, The DBLP Computer Science Bibliography and The HCI Bibliography.

More information about this series at <http://www.springer.com/series/6033>

Martin Schmettow

New Statistics for Design Researchers

A Bayesian Workflow in Tidy R



Springer

Martin Schmettow
Cognition, Data & Education
University of Twente
Enschede, The Netherlands

ISSN 1571-5035 ISSN 2524-4477 (electronic)
Human–Computer Interaction Series
ISBN 978-3-030-46379-3 ISBN 978-3-030-46380-9 (eBook)
<https://doi.org/10.1007/978-3-030-46380-9>

© Springer Nature Switzerland AG 2021

This work is subject to copyright. All rights are reserved by the Publisher, 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 any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, 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.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*This book is dedicated to my father,
Dr. Walter Schmettow, with love.
Ask me and I will read it to you.*

*And to my daughter, Eli, with all my love.
Your songs are another book.*

Contents

Part I Preparations

1	Introduction	3
1.1	Whom This Book Is For	3
1.2	Quantitative Design Research	4
1.3	What Is New Statistics?	7
1.4	How to Use This Book	11
1.4.1	Routes	12
1.4.2	In the Classroom	13
1.4.3	The Stone of Rosetta	15
1.5	Thank You and Supplementary Readings	21
References		22
2	Getting Started with R	23
2.1	Setting up the R Environment	24
2.1.1	Installing CRAN Packages	26
2.1.2	Installing Packages from GitHub	27
2.1.3	A First Statistical Program	28
2.1.4	Bibliographic Notes	30
2.2	Learning R: A Primer	31
2.2.1	Assigning and Calling Objects	34
2.2.2	Vectors	35
2.2.3	Basic Object Types	36
2.2.4	Operators and Functions	39
2.2.5	Storing Data in Data Frames	42
2.2.6	Import, Export and Archiving	46
2.2.7	Case Environments	48
2.2.8	Structuring Data	51
2.2.9	Data Transformation	53
2.2.10	Plotting Data	55

2.2.11	Fitting Regression Models	63
2.2.12	Knitting Statistical Reports	65
2.3	Further Reading	67
	Reference	68
3	Elements of Bayesian Statistics	69
3.1	Rational Decision-Making in Design Research	70
3.1.1	Measuring Uncertainty	73
3.1.2	Benchmarking Designs	76
3.1.3	Comparison of Designs	80
3.1.4	Prior Knowledge	83
3.2	Observations and Measures	87
3.2.1	Interaction Sequences	87
3.2.2	Performance Measures	89
3.2.3	Satisfaction and Other Feelings	90
3.3	Descriptive Statistics	92
3.3.1	Frequencies	93
3.3.2	Central Tendency	95
3.3.3	Dispersion	97
3.3.4	Associations	101
3.4	Bayesian Probability Theory	110
3.4.1	Some Set Theory	111
3.4.2	Probability	116
3.4.3	Likelihood	120
3.4.4	Bayesian and Frequentist Probability	126
3.4.5	Bayes' Theorem	128
3.4.6	Bayesian Dynamics of Belief	131
3.5	Statistical Models	133
3.5.1	The Structural Part	134
3.5.2	Distributions: Shapes of Randomness	136
3.6	Toward Bayesian Estimation	161
3.7	On Priors and Defaults	165
3.8	Further Readings	166
	References	167

Part II Models

4	Basic Linear Models	171
4.1	Quantification at Work: Grand Mean Models	172
4.1.1	Do the Random Walk: Markov Chain Monte Carlo Sampling	177
4.1.2	Likelihood and Random Term	180
4.1.3	Working with the Posterior Distribution	181
4.1.4	Center and Interval Estimates	184

4.2	Walk the Line: Linear Regression	188
4.2.1	Transforming Measures	191
4.2.2	Correlations	199
4.2.3	Endlessly Linear	202
4.3	Factorial Models	203
4.3.1	A Versus B: Comparison of Groups	204
4.3.2	Not Stupid: Dummy Variables	207
4.3.3	Treatment Contrast Coding	208
4.3.4	Absolute Means Model	210
4.3.5	Ordered Factorial Models	212
5	Multi-predictor Models	219
5.1	On Surface: Multiple Regression Models	219
5.2	Crossover: Multifactorial Models	225
5.3	Line-by-Line: Grouped Regression Models	227
5.4	Conditional Effects Models	230
5.4.1	Conditional Multiple Regression	231
5.4.2	Conditional Multifactorial Models	233
5.4.3	Saturation: Hitting the Boundaries	239
5.4.4	Amplification: More than the Sum	249
5.4.5	Conditional Effects and Design Theory	253
5.5	Doing the Rollercoaster: Polynomial Regression Models	256
5.5.1	Make Yourself a Test Statistic	263
5.6	Further Readings	265
	References	266
6	Multilevel Models	267
6.1	The Human Factor: Intercept Random Effects	268
6.2	Multi-level Linear Regression: Variance in Change	274
6.3	Thinking Multi-level	280
6.4	Testing Universality of Theories	286
6.5	Non-human Populations and Cross-Overs	292
6.6	Nested Random Effects	298
6.7	What Are Random Effects? On Pooling and Shrinkage	302
6.8	Psychometrics and Design-o-Metric Models	307
6.8.1	Coverage	312
6.8.2	Reliability	314
6.8.3	Validity	318
6.8.4	Towards Design-o-Metrix	318
6.9	Further Readings	321
	References	322

7 Generalized Linear Models	323
7.1 Elements of Generalized Linear Models	326
7.1.1 Re-linking Linearity	327
7.1.2 Choosing Patterns of Randomness	331
7.1.3 Mean-Variance Relationship	333
7.2 Count Data	338
7.2.1 Poisson Regression	338
7.2.2 Logistic (aka Binomial) Regression	347
7.2.3 Modeling Overdispersion	355
7.3 Duration Measures	365
7.3.1 Exponential and Gamma Regression	365
7.3.2 ExGaussian Regression	369
7.4 Rating Scales	381
7.4.1 Ordered Logistic Regression	385
7.4.2 Beta Regression	388
7.5 Beyond Mean: Distributional Models	391
7.5.1 Item-Level Anchoring in Rating Scales	391
7.5.2 Participant-Level Employment of Scale	394
7.5.3 Participant-Level Skew in Reaction Times	395
7.6 Further Readings	398
References	399
8 Working with Models	401
8.1 Model Criticism	402
8.1.1 Residual Analysis	402
8.1.2 Fitted Responses Analysis	415
8.2 Model Comparison	422
8.2.1 The Problem of Overfitting	422
8.2.2 Cross Validation and LOO	425
8.2.3 Information Criteria	430
8.2.4 Model Selection	433
8.2.5 Comparing Response Distributions	434
8.2.6 Testing Hypotheses	436
8.2.7 A Note on Bayes Factor	438
8.3 Further Readings	438
References	439
Appendix: Cases	441