

Information Visualization

Robert Spence

Information Visualization

An Introduction

Third Edition



Springer

Robert Spence
Department of Electrical and Electronic
Engineering
Imperial College London
London, UK

The front cover colour image is derived from a photograph (courtesy of Neville Miles LRPS) of a mosaic created by the author to illustrate the concepts of distortion and degree of interest (see Fig. 4.12). The monochrome pattern at the top of the front cover is associated with the floating mode of RSVP.

Additional material to this book can be downloaded from <http://extras.springer.com>

ISBN 978-3-319-07340-8 ISBN 978-3-319-07341-5 (eBook)

DOI 10.1007/978-3-319-07341-5

Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014951001

1st edition: © ACM Press 2001

2nd edition: © Pearson Education Ltd 2007

© Springer International Publishing Switzerland 2014

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. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

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.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

To Robert and Merin



for their love and support

Preface to Third Edition

Who Is the Book For?

Despite conventional – and misplaced – views about information visualization, this book is *not* targeted solely at computer science students: visualization basically has nothing to do with computer science¹ and is far too powerful and important to so many disciplines for it to be confined to such a small audience. Rather, the book is intended as an introduction to information visualization for first year (or later) students of *any* discipline, be it medicine, marketing, geology, security or demographics. Those students may be encountering the subject in their first university year or, following a Masters degree in any subject, they may be training to be visual and interaction designers. In fact, the book material has been extensively tested through presentation to many such students in the UK, The Netherlands, Portugal and elsewhere. For the same reason it does not attempt to bring you the latest results of research, though it remains topical and even looks ahead at what might be possible.

What's New?

In one sense, nothing. As in the second edition, the structure of the book can be represented by a ‘Tube-like’ model (Fig. P1) emphasizing three principal topics – representation, presentation and interaction – and reflecting the generally accepted ‘reference model’ of the information visualization process (Fig. P2). But the content of each of these principal chapters has undergone major revision.

¹A provocative statement indeed, but one made (1) in full appreciation of the enormous benefits than can accrue from computation, and (2) to emphasise that visualization is essentially – and by definition – the formation of a mental model of something.

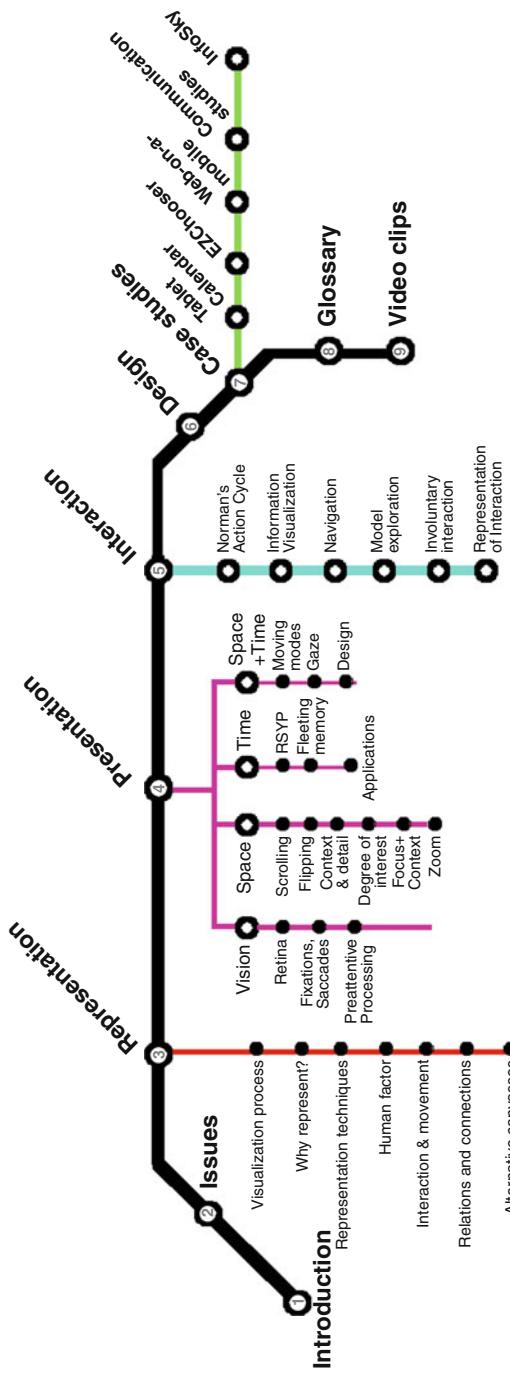


Fig.P1 The structure of the book

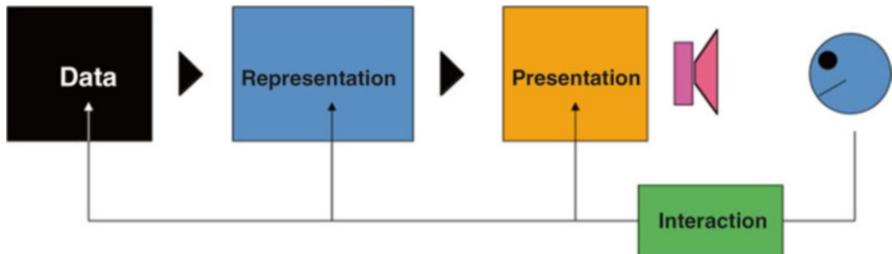


Fig. P2 The reference model of the information visualization process. The representation, presentation and interaction processes are the subjects of the principal Chaps. 3, 4 and 5 of the book. Consideration of the human user, pictured at *right*, proceeds throughout the book

The material on representation has been given a structure that will hopefully lead to better understanding. Presentation has been addressed by recognising three principal resources available to the designer: the human visual system, the constraints and freedoms associated with display space, and considerations of the time allocated to a task. The chapter on interaction has been completely rewritten. Although many researchers are seeking a science of interaction they have not yet found it, so I have adopted Norman's Cycle of Interaction for the powerful structure and guidance that it offers to those who have to design interactive systems.

Human Performance

Many visualization tools are proposed without much, if any, recognition of the fact that they are basically there to support a human activity – the formation of a mental model of something (i.e., visualization) or, put another way, making sense of data. What I have tried to do is distil, from the vast existing (and incomplete) knowledge of human perception and cognition, those aspects that are principally relevant to a user's attempts to form a mental model of some data. And I have tried to illustrate by practical examples *why* that distilled knowledge is relevant.

Creative Design

Two beliefs direct my teaching and are reflected in the book. First, I believe that the best way to gain an understanding of human-computer interaction, and information visualization in particular, is to *do it*. I decline to set end-of-term examination papers; I feel it is far more effective pedagogically to ask my students to undertake design exercises of varying complexity, ending with a substantial group project. Second, I focus on creative design, and certainly not on implementation: you will

find no exercises beginning “Write a program for . . .”. Consistent with these ideals I try to place my design projects in a realistic setting. Thus, the group project that terminates a course treats each small group of students as a design consultancy working on a commission from a client, ending with an oral and written presentation to that client. The enthusiasm generated by this opportunity to be creative and imaginative is apparent from the feedback I receive.

Teaching Resources

For many years I have made the powerpoint files and other materials I employ in my teaching freely available to teachers, and will continue to do so (just contact me at r.spence@imperial.ac.uk).

Visual Analytics

Experts in information visualization will no doubt wonder how I have addressed the “new” topic of visual analytics. I haven’t or, rather, I have briefly discussed the *context* of information visualization in Chap. 1 (Introduction) and provided two illustrative examples of what would be termed visual analytics. There is one principal reason: the book is intended as an *introduction* to information visualization, and there is plenty of material to absorb and experience, in a typical course, with just that single end in view. In any case, I am sure that a competent instructor will be able, if they wish, to introduce a flavour of visual analytics, perhaps without even mentioning it by name. Certainly, following an introductory course on information visualization there are many pedagogical paths that would introduce visual analytics, but it is certainly not for me to prescribe one that should be followed.

London, UK
June 2014

Bob Spence

Acknowledgements

The development of this third edition has, like that of the first two, benefited immensely from interaction with my students, and to them I am most grateful. They include those graduates of many disciplines (20 each year for 14 years) who chose to become professional interaction designers and attended my course at the Technical University of Eindhoven in The Netherlands. They also include my first-year students at Imperial College London. And they now include students studying for a number of postgraduate options at the University of Madeira, Portugal. I wish I could list you all by name – but then you know who you are.

I have also benefitted from careful reviews of parts of the book, reviews that have led to what I believe to be improvements. For this I am most grateful to Randy Goebel (Calgary, Canada), Harri Siirtola (Tampere, Finland), Mark Apperley (Hamilton, New Zealand) and Mark Witkowski (London, England).

There are many others who have made valuable contributions and have influenced my thinking about information visualization in many different ways. They include Dr. Brock Craft (who also took the photo of Jacques Bertin), Oscar de Bruijn, Jeremy Pitt, Kent Wittenberg, Par-Anders Andersson, Sheelagh Carpendale, Joost de Folter, Tim Cribbens, James Mardell, Ravinder Bhogal, Andrew Spence, Robert Michael Spence, Petr Kosnar and Ollie Ford.

Work on many aspects of the book was facilitated by the Award of a Leverhulme Emeritus Fellowship for which I am most grateful. It is also my great good fortune that my research and writing was carried out in the congenial and stimulating environment of the Department of Electrical and Electronic Engineering at Imperial College London.

I could not wish for a more supportive and efficient Editor than Beverley Ford who seemed to respond to queries within milliseconds. She and James Robinson guided me expertly through the process of getting this book published, and my grateful thanks goes to both of them.

Writing a book can lead to one becoming a somewhat unsociable character at times, and the forbearance of those around me is therefore much appreciated. Again, they know who they are!

London, UK
June 2014

Bob Spence

Contents

1	Introduction	1
1.1	Home Finding	1
1.2	History.....	3
1.2.1	Florence Nightingale.....	3
1.2.2	Travelling on the Tube	5
1.2.3	Napoleon's March to Moscow	7
1.2.4	Cholera.....	7
1.3	Back to Home Finding	10
1.4	Is Information Visualization Worthwhile?	12
1.4.1	Mortgage Fraud.....	12
1.4.2	Drug Design	13
1.4.3	Silicon Chips.....	14
1.5	Why Do We Need a Book About Information Visualization?	14
1.5.1	Variables.....	14
1.5.2	Canvasses	15
1.5.3	Tasks.....	15
1.5.4	Perception and Cognition.....	15
1.5.5	The Design Challenge.....	16
1.5.6	Context.....	16
	Exercises	19
	Exercise 1.1	19
	Exercise 1.2	19
	Exercise 1.3	19
	Exercise 1.4	19
	References.....	19
2	Issues	21
2.1	A Task	21
2.2	Fuzzy Goals	22
2.3	The Data.....	22
2.4	Table Presentation	23

2.5	Derived Data	23
2.6	Alternative Representations	25
2.7	Adding a Representation.....	26
2.8	Multiple Attributes	27
2.9	Attribute Specification	27
2.10	Display Space Limitations	28
2.11	Mental Models	29
2.12	Near Misses.....	29
2.13	Time	30
2.14	Archives	33
2.15	Unwanted Information	33
2.16	Movement	35
2.17	Conclusion	36
2.18	Remainder of the Book	37
	Exercises	38
	Exercise 2.1	38
	Exercise 2.2.....	38
	Exercise 2.3.....	38
	Exercise 2.4.....	38
	References.....	38
3	Representation.....	41
3.1	The Information Visualization Process	41
3.2	Why Do We Represent?.....	42
3.3	A Brief Introduction to Some Representation Techniques	43
	3.3.1 Dials	43
	3.3.2 Point Representation	44
	3.3.3 Scatterplots.....	44
	3.3.4 Patterns.....	46
	3.3.5 Star Plots	46
	3.3.6 Magnification	47
	3.3.7 Parallel Coordinate Plots.....	49
	3.3.8 Iconic Representation.....	50
	3.3.9 Mosaic Plots.....	51
	3.3.10 Chernoff Faces	53
	3.3.11 Text.....	53
	3.3.12 Time-Varying Data.....	54
	3.3.13 Closing Note	56
3.4	The Human Factor	56
	3.4.1 Change Blindness.....	57
	3.4.2 Perception of Value	59
	3.4.3 Object and Attribute Visibility	63
3.5	Interaction	66
	3.5.1 Reordering.....	67
	3.5.2 Filtering.....	67
	3.5.3 Parallel Coordinate Plots.....	68

3.5.4	Brushed Histograms.....	71
3.5.5	Bargrams	74
3.5.6	Scatterplot Matrices	75
3.5.7	Summary	79
3.6	Relations and Connections.....	80
3.6.1	General Networks	80
3.6.2	Hierarchies	93
3.7	Alternative Canvasses	101
	Exercises	105
	Exercise 3.1	105
	Exercise 3.2.....	106
	Exercise 3.3.....	106
	Exercise 3.4.....	106
	Exercise 3.5.....	107
	Exercise 3.6.....	107
	Exercise 3.7.....	107
	Exercise 3.8.....	108
	Exercise 3.9.....	108
	Exercise 3.10.....	108
	Exercise 3.11.....	108
	References.....	108
4	Presentation	111
4.1	Human Vision.....	112
4.1.1	Retinal Image	112
4.1.2	Fixations and Saccades	113
4.1.3	Preattentive Processing	114
4.1.4	Summary	116
4.2	Presentation in Space	116
4.2.1	Extent	117
4.2.2	Scrolling.....	118
4.2.3	Flipping	119
4.2.4	Context and Detail	123
4.2.5	Degree of Interest.....	126
4.2.6	Focus Plus Context.....	129
4.2.7	Zoom: Geometric and Semantic	140
4.3	Temporal Considerations	143
4.3.1	Rapid Serial Visual Presentation	144
4.3.2	Fleeting Memory.....	146
4.3.3	Applications	146
4.3.4	Assessment of Slide-Show RSVP	149
4.4	Presentation in Space and Time	149
4.4.1	Moving RSVP Modes	150
4.4.2	Eye Gaze	153
4.4.3	Design Considerations	160

4.5	Representation of Presentation	166
	Exercises	167
	Exercise 4.1	167
	Exercise 4.2	167
	Exercise 4.3	167
	Exercise 4.4	167
	Exercise 4.5	167
	Exercise 4.6	168
	Exercise 4.7	168
	References.....	169
5	Interaction	173
5.1	Norman's Action Cycle.....	174
	5.1.1 The Goal.....	176
	5.1.2 The Gulf of Execution	176
	5.1.3 The Gulf of Evaluation	181
	5.1.4 The Following Sections	183
5.2	Interaction for Information Visualization.....	183
	5.2.1 A Goal.....	184
	5.2.2 Formation of an Intention	184
	5.2.3 Alteration of the Goal	185
	5.2.4 Formation of an Action Plan	186
	5.2.5 Trade-Offs, Correlations and Overviews	188
	5.2.6 Interpretation.....	191
	5.2.7 Evaluation	191
	5.2.8 Summary	192
	5.2.9 Assessment in Context	192
	5.2.10 Design Freedom.....	192
5.3	Interaction for Navigation.....	193
	5.3.1 Getting Lost	194
	5.3.2 Formulation of an Action Plan	195
	5.3.3 Clarity and Ambiguity.....	195
	5.3.4 Menu Structure.....	197
	5.3.5 Sensitivity.....	198
	5.3.6 Breadcrumbs	200
	5.3.7 Scent.....	202
	5.3.8 Visual Momentum.....	203
5.4	Interaction with Models	204
	5.4.1 Immediacy of Interest	204
	5.4.2 Dynamic Exploration	204
	5.4.3 Availability of Data.....	207
	5.4.4 Models.....	208
	5.4.5 The Design of a Light Bulb	210
	5.4.6 The Influence Explorer	213
	5.4.7 Alternative Representations of Derived Data.....	215

5.5	Involuntary Interaction.....	217
5.5.1	Involuntary Browsing.....	218
5.6	Representation of Interaction	221
	Exercises	222
	Exercise 5.1	222
	Exercise 5.2	222
	Exercise 5.3	222
	Exercise 5.4	222
	References.....	222
6	Design	225
6.1	A Very Personal View	225
6.2	An Attitude.....	225
6.3	A Commission	226
6.4	Idea Generation.....	226
6.5	Who Is the User?.....	227
6.6	Convergence.....	228
6.7	Sketching.....	230
6.8	Design	231
6.9	Evaluation	231
6.10	Oral Presentation to Client.....	232
	Exercises	234
	References.....	235
7	Case Studies.....	237
7.1	Small Interactive Calendars	239
7.1.1	Planning Your Time.....	239
7.1.2	Design Philosophy	240
7.1.3	Background.....	240
7.1.4	Calendar Views	243
7.1.5	Interactive Control	243
7.1.6	Search.....	245
7.1.7	Usability Study.....	245
7.1.8	Observations.....	246
7.1.9	Satisfaction and Preference.....	247
7.1.10	Usability	248
7.1.11	Potential Developments	248
7.2	Selecting One from Many	251
7.2.1	The Problem.....	251
7.2.2	The Task	252
7.2.3	Existing Solutions	252
7.2.4	Bargrams	253
7.2.5	Affordances	255
7.2.6	EZChooser	255
7.2.7	Sensitivity.....	256
7.2.8	Related Work.....	258

7.2.9	Evaluation	260
7.2.10	Comment.....	260
7.2.11	Recent Development.....	261
7.2.12	Evaluation	262
7.3	Web Browsing Through a Keyhole	263
7.3.1	Seeking News.....	263
7.3.2	The Problem.....	264
7.3.3	A Solution	265
7.3.4	The RSVP Browser.....	266
7.3.5	System Design	268
7.3.6	Evaluation	270
7.3.7	Discussion	272
7.3.8	Comment.....	273
7.4	Communication Analysis	274
7.4.1	Command and Control	274
7.4.2	System Requirements.....	274
7.4.3	The MIND Tool	275
7.4.4	Exploratory Analysis.....	275
7.4.5	Scenario.....	276
7.4.6	Football	277
7.4.7	Conclusion	278
7.5	Archival Galaxies.....	279
7.5.1	Large Collections of Documents.....	279
7.5.2	Background and Requirements	280
7.5.3	Earlier Work	280
7.5.4	Design Decisions	283
7.5.5	Interaction and Search.....	286
7.5.6	Layout	286
7.5.7	Evaluation	287
Exercises	290	
Design 1 Flower Power.....	290	
Design 2 What's Interesting?	290	
Design 3 Rail Travel	290	
Design 4 Find that Photo.....	291	
Design 5 Journal Search.....	291	
Design 6 Postgraduate Study	291	
Design 7 Travel by Bus.....	291	
Design 8 Online Shopping	291	
Design 9 The Web on a Mobile.....	292	
Design 10 Email Records and Their Exploration	292	
Design 11 Mobiles for Very Young Children	292	

Appendix	293
Videos	293
V1 Qualitative Representation	294
Background	294
Action.....	294
Illustrates.....	295
Notes	295
V2 Dynamic Exploration of Relationships	295
Background	295
Action.....	295
Illustrates.....	296
V3 Encoding by Sound: A Brain Tumour.....	296
Background	296
Action.....	296
Illustrates.....	296
V4 Visualization 2020 AD	296
Background	297
Action.....	297
Illustrates.....	297
V5 Attribute Explorer.....	297
Background	297
Action.....	298
Illustrates.....	298
V6 Attribute Explorer: A Short Demo	298
Background	298
Action.....	298
Illustrates.....	299
V7 Infocanvas	299
Background	299
Action.....	299
V8 Interactive Venn Diagram.....	299
Background	300
Action.....	300
Illustrates.....	300
V9 The Cone Tree	300
Background	300
Action.....	301
Illustrates.....	301
V10 Fundexplorer	301
Background	301
Action.....	301
Illustrates.....	302
V11 Bifocal Display I	302
Background	302
Action.....	302
Illustrates.....	302

V12 Bifocal Display II.....	302
Background	303
Action.....	303
Illustrates.....	303
V13 Flip Zoom on a Mobile	303
Background	303
Action.....	303
Illustrates.....	304
V14 Distorted Map on a PDA.....	304
Background	304
Action.....	304
Illustrates.....	304
V15 Pliable Display Technology on a Table.....	304
Background	305
Action.....	305
Illustrates.....	305
V16 Rubber Sheet Map Distortion	305
Background	305
Action.....	306
Illustrates.....	306
V17 The Perspective Wall.....	306
Background	306
Action.....	306
Illustrates.....	306
V18 Sunburst.....	307
Background	307
Action.....	307
Illustrates.....	307
V19 Combined Zoom and Pan.....	307
Background	308
Action.....	308
Illustrates.....	308
V20 Floating RSVP	308
Background	308
Action.....	308
Illustrates.....	309
V21 Image Browsing – Video on Demand	309
Background	309
Action.....	309
Illustrates.....	309
V22 Navigation via a Small Display.....	309
Background	310
Action.....	310
Illustrates.....	310

V23 to V28 Image Presentation Modes	310
Background	310
Action.....	311
Illustrates.....	311
V29 Involuntary Browsing with a Coffee Table	311
Background	311
Action.....	311
Illustrates.....	312
V30 Discovery via Dynamic Representation.....	312
Background	312
Action.....	312
Illustrates.....	312
V31 Influence Explorer.....	312
Background	313
Action.....	313
Illustrates.....	313
V32 Model Maker.....	313
Background	313
Action.....	314
Illustrates.....	314
Notes	314
V33 Human Guidance of Automated Design	314
Background	314
Action.....	315
Illustrates.....	315
V34 Prosecution Matrix	315
Background	315
Action.....	316
Illustrates.....	316
V35 Dust And Magnet	316
Background	316
Action.....	316
Illustrates.....	316
V36 RSVP Browser	317
Background	317
Action.....	317
Illustrates.....	317
V37 Infosky Visual Explorer	317
Background	318
Action.....	318
Illustrates.....	318
Glossary	319