

Commenced Publication in 1973

Founding and Former Series Editors:

Gerhard Goos, Juris Hartmanis, and Jan van Leeuwen

Editorial Board

David Hutchison

Lancaster University, Lancaster, UK

Takeo Kanade

Carnegie Mellon University, Pittsburgh, PA, USA

Josef Kittler

University of Surrey, Guildford, UK

Jon M. Kleinberg

Cornell University, Ithaca, NY, USA

Friedemann Mattern

ETH Zurich, Zurich, Switzerland

John C. Mitchell

Stanford University, Stanford, CA, USA

Moni Naor

Weizmann Institute of Science, Rehovot, Israel

C. Pandu Rangan

Indian Institute of Technology Madras, Chennai, India

Bernhard Steffen

TU Dortmund University, Dortmund, Germany

Demetri Terzopoulos

University of California, Los Angeles, CA, USA

Doug Tygar

University of California, Berkeley, CA, USA

Gerhard Weikum

Max Planck Institute for Informatics, Saarbrücken, Germany

More information about this series at <http://www.springer.com/series/7409>

Kim Marriott · Falk Schreiber
Tim Dwyer · Karsten Klein
Nathalie Henry Riche · Takayuki Itoh
Wolfgang Stuerzlinger · Bruce H. Thomas (Eds.)

Immersive Analytics

Editors

Kim Marriott
Monash University
Melbourne, VIC, Australia

Falk Schreiber
University of Konstanz
Konstanz, Germany

Tim Dwyer
Monash University
Melbourne, VIC, Australia

Karsten Klein
University of Konstanz
Konstanz, Germany

Nathalie Henry Riche
Microsoft
Redmond, WA, USA

Takayuki Itoh
Ochanomizu University
Tokyo, Japan

Wolfgang Stuerzlinger
Simon Fraser University
Surrey, BC, Canada

Bruce H. Thomas
University of South Australia
Adelaide, SA, Australia

ISSN 0302-9743 ISSN 1611-3349 (electronic)
Lecture Notes in Computer Science
ISBN 978-3-030-01387-5 ISBN 978-3-030-01388-2 (eBook)
<https://doi.org/10.1007/978-3-030-01388-2>

Library of Congress Control Number: Applied For

LNCS Sublibrary: SL3 – Information Systems and Applications, incl. Internet/Web, and HCI

© Springer Nature Switzerland AG 2018

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, express 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.

Cover illustration: The illustration on the cover appears in this volume on p. 2, used with permission.

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

Foreword

We live in an age where the amount and complexity of data available to us far surpass our ability to understand or to utilise them in decision-making. Analysis of such data is not only common in the physical, social, and life sciences, but is becoming an integral part of effective planning in business, government, e-health, and many other aspects of modern society. Furthermore data analytics is no longer solely the preserve of scientists and professional analysts as personalised data analytics becomes increasingly common.

Visual analytics has become a key technology for human-in-the-loop data analysis. While the standard definition for visual analytics is agnostic of the actual interface devices employed by visual analytics systems, the affordances of the display and input devices used for analysing data strongly affect the experience of the users of such systems and, thereby, their degree of engagement and productivity. For practical visual analytics tools, the platform for interaction is almost always a standard desktop computer. A systematic approach to developing analysis and decision support tools that move beyond the desktop is lacking.

Immersive analytics is a new interdisciplinary field that brings together researchers and practitioners from data visualisation, visual analytics, virtual and mixed reality, human–computer interaction, and human-in-the-loop algorithmics to explore these new forms of analytics tools. The goal is to remove barriers between people, their data, and the tools they use for analysis by developing more engaging, embodied analysis tools that support data understanding and decision-making everywhere and by everyone, either working individually or collaboratively.

This book is the outcome of two coordinated workshops on immersive analytics held in 2016. The first in Shonan, Japan, took place in February and organised by Takayuki Itoh, Kim Marriott, Falk Schreiber, and Uwe Wössner with the help of Karsten Klein, the second was held in June at Dagstuhl, Germany, and was organised by Tim Dwyer, Nathalie Henry Riche, Wolfgang Stuerzlinger, and Bruce H. Thomas, again with the help of Karsten Klein. In all, 25 leading international experts in data visualisation, visual analytics, human–computer interaction, virtual reality and augmented reality attended the first workshop, with another 38 experts attending the second. There was a sizeable overlap of experts between the two workshops that provided a sensible continuity of concepts.

The two workshops explored the definition of immersive analytics and identified the structure and focus of this book. A working group for each chapter was formed at the workshops, with the participation of invited experts as needed, and the groups wrote the chapters contained in this book. A critical goal was to develop a vision of the research domain for immersive analytics and a roadmap for future investigations. Authors submitted manuscripts for their chapters in mid-2017. These initial versions were first reviewed “internally” by one of the book editors. After an initial round of revision based on these internal reviews, the updated manuscripts were sent to expert

reviewers invited from the community. We are grateful to these people for their detailed and insightful reviews.

September 2018

Kim Marriott
Falk Schreiber
Tim Dwyer
Karsten Klein
Nathalie Henry Riche
Takayuki Itoh
Wolfgang Stuerzlinger
Bruce H. Thomas

Table of Contents

| | |
|--|-----|
| 1. Immersive Analytics: An Introduction | 1 |
| <i>Tim Dwyer, Kim Marriott, Tobias Isenberg, Karsten Klein, Nathalie Riche, Falk Schreiber, Wolfgang Stuerzlinger, and Bruce H. Thomas</i> | |
| 1.1. What is Immersive Analytics? | 1 |
| 1.2. Historical Context | 4 |
| 1.3. Engagement and Immersion | 10 |
| 1.4. Overview of this Book | 14 |
| 1.5. Research Agenda | 15 |
| 2. Immersive Analytics: Time to Reconsider the Value of 3D for Information Visualisation | 25 |
| <i>Kim Marriott, Jian Chen, Marcel Hlawatsch, Takayuki Itoh, Miguel A. Nacenta, Guido Reina, and Wolfgang Stuerzlinger</i> | |
| 2.1. Introduction | 25 |
| 2.2. Background: Perception and Presentation of 3D | 29 |
| 2.3. Prior Research Comparing 2D with 3D Representations | 35 |
| 2.4. Potential Benefits of Immersive Visualisation | 42 |
| 2.5. Research Questions and Issues | 46 |
| 2.6. Conclusion | 48 |
| 3. Multisensory Immersive Analytics | 57 |
| <i>Jon McCormack, Jonathan C. Roberts, Benjamin Bach, Carla Dal Sasso Freitas, Takayuki Itoh, Christophe Hurter, and Kim Marriott</i> | |
| 3.1. Introduction | 57 |
| 3.2. Multisensory Presentation and Analysis | 59 |
| 3.3. A Framework for Multisensorial Immersive Analytics | 61 |
| 3.4. Visual Presentation | 63 |
| 3.5. Sonification and Auralization | 65 |
| 3.6. Haptic Displays | 69 |
| 3.7. Smell/Olfaction, Taste/Gustation | 77 |
| 3.8. Designing Multisensorial Immersive Systems | 78 |
| 3.9. Discussion and Research Challenges | 85 |
| 3.10. Conclusion | 87 |
| 4. Interaction for Immersive Analytics | 95 |
| <i>Wolfgang Büschel, Jian Chen, Raimund Dachselt, Steven Drucker, Tim Dwyer, Carsten Görg, Tobias Isenberg, Andreas Kerren, Chris North, and Wolfgang Stuerzlinger</i> | |
| 4.1. Introduction | 95 |
| 4.2. Opportunities and Requirements | 98 |
| 4.3. Basic Tasks for Analytics | 104 |

| | |
|---|-----|
| 4.4. Natural User Interfaces (NUI) and Post WIMP Interaction | 106 |
| 4.5. Designing Interactions for Immersive Analytics | 114 |
| 4.6. Archetypal Setups | 116 |
| 4.7. Example Systems | 121 |
| 4.8. Conclusion | 126 |
| 5. Immersive Human-Centered Computational Analytics | 139 |
| <i>Wolfgang Stuerzlinger, Tim Dwyer, Steven Drucker, Carsten Görg, Chris North, and Gerik Scheuermann</i> | |
| 5.1. Introduction | 139 |
| 5.2. Analytics Process | 141 |
| 5.3. Collaboration between Humans and Automated Processes | 148 |
| 5.4. Challenges | 152 |
| 5.5. Conclusion | 158 |
| 6. Immersive Visual Data Stories | 165 |
| <i>Petra Isenberg, Bongshin Lee, Huamin Qu, and Maxime Cordeil</i> | |
| 6.1. Introduction | 165 |
| 6.2. Visual Data-Driven Stories | 166 |
| 6.3. Defining Immersion in Visual Data Stories | 171 |
| 6.4. Research Opportunities in Immersive Visual Storytelling with Data | 177 |
| 6.5. Conclusion | 180 |
| 7. Situated Analytics | 185 |
| <i>Bruce H. Thomas, Gregory F. Welch, Pierre Dragicevic, Niklas Elmqvist, Pourang Irani, Yvonne Jansen, Dieter Schmalstieg, Aurélien Tabard, Neven A. M. ElSayed, Ross T. Smith, and Wesley Willett</i> | |
| 7.1. Introduction | 185 |
| 7.2. Characterization of Situated Visualizations | 191 |
| 7.3. Examples of Situated Analytics | 199 |
| 7.4. Blended Situated Analytics Controls | 202 |
| 7.5. Design Considerations for Situated Analytics Systems | 207 |
| 7.6. Challenges and Research Agenda | 212 |
| 7.7. Future Work | 214 |
| 7.8. Conclusion | 216 |
| 8. Collaborative Immersive Analytics | 221 |
| <i>Mark Billinghurst, Maxime Cordeil, Anastasia Bezerianos, and Todd Margolis</i> | |
| 8.1. Introduction | 221 |
| 8.2. Definition and Scope | 224 |
| 8.3. Collaboration Over Space and Time | 226 |
| 8.4. Types of Participants in CIA | 235 |
| 8.5. Interaction in CIA Environments | 238 |
| 8.6. Opportunities for Research | 243 |
| 8.7. Conclusion | 247 |

| | |
|---|-----|
| 9. Just 5 Questions: Toward a Design Framework for Immersive Analytics | 259 |
| <i>Kim Marriott, Jian Chen, Marcel Hlawatsch, Takayuki Itoh, Miguel A. Nacenta, Guido Reina, and Wolfgang Stuerzlinger</i> | |
| 9.1. Introduction | 259 |
| 9.2. Design Frameworks for Data Visualisation & Visual Analytics | 261 |
| 9.3. Architecture of IA Applications | 262 |
| 9.4. The 5 Question Design Framework for IA | 263 |
| 9.5. Using the Design Space Framework | 272 |
| 9.6. Research Questions and Issues | 282 |
| 9.7. Conclusion | 284 |
| 10. Immersive Analytics Applications in Life and Health Sciences | 289 |
| <i>Tobias Czauderna, Jason Haga, Jinman Kim, Matthias Klapperstück, Karsten Klein, Torsten Kuhlen, Steffen Oeltze-Jafra, Björn Sommer, and Falk Schreiber</i> | |
| 10.1. Background | 289 |
| 10.2. Case Study 1: Molecular Scientific Visualisation in Structural Biology | 291 |
| 10.3. Case Study 2: Explorative Analysis of <i>In-Silico</i> Experiments in Neuroscience | 294 |
| 10.4. Case Study 3: Exploration of Virtual Cells in Cytology | 297 |
| 10.5. Case Study 4: Image Analytics in Medicine | 303 |
| 10.6. Case Study 5: Population Study Analytics in Epidemiology | 309 |
| 10.7. Case Study 6: Collaborative Immersive Analytics in Life and Health Sciences | 315 |
| 10.8. Challenges and Outlook | 320 |
| 11. Exploring Immersive Analytics for Built Environments | 331 |
| <i>Tom Chandler, Thomas Morgan, and Torsten Wolfgang Kuhlen</i> | |
| 11.1. Introduction and Overview | 331 |
| 11.2. Case Study 1: Planning and Visualisation in Production Engineering | 332 |
| 11.3. Case Study 2: Immersive Analytics in the Interactive Visualisation of Sustainable Cities | 338 |
| 11.4. Case Study 3: Crowd Simulations in a Virtual Model of Medieval Angkor | 346 |
| 11.5. Conclusion | 354 |

Contributors

Benjamin Bach University of Edinburgh, Edinburgh, UK

Anastasia Bezerianos Inria and Universite Paris-Saclay, Paris, France

Mark Billinghurst University of South Australia, Mawson Lakes, Australia

Wolfgang Büschel Technische Universität Dresden, Dresden, Germany

Tom Chandler Monash University, Melbourne, Australia

Jian Chen The Ohio State University, Columbus, USA

Maxime Cordeil Monash University, Melbourne, Australia

Tobias Czauderna Monash University, Melbourne, Australia

Raimund Dachse Technische Universität Dresden, Dresden, Germany

Pierre Dragicevic Inria, Rocquencourt, France

Steven Drucker Microsoft Research, Redmond, USA

Tim Dwyer Monash University, Melbourne, Australia

Neven A. M. ElSayed Benha University, Benha, Egypt

Niklas Elmqvist University of Maryland, College Park, USA

Carla Dal Sasso Freitas Federal University of Rio Grande do Sul, Porto Alegre, Brazil

Carsten Görg University of Colorado, Denver, USA

Jason Haga National Institute of Advanced Industrial Science and Technology, Tokyo, Japan

Marcel Hlawatsch University of Stuttgart, Stuttgart, Germany

Christophe Hurter Ecole Nationale de l'Aviation Civile (ENAC), Toulouse, France

Pourang Irani University of Manitoba, Winnipeg, Canada

Petra Isenberg Inria, Paris, France

Tobias Isenberg Inria and University Paris-Saclay, Paris, France

Takayuki Itoh Ochanomizu University, Tokyo, Japan

Yvonne Jansen Sorbonne University, Paris, France

Andreas Kerren Linnaeus University, Växjö, Sweden

Jimman Kim University of Sydney, Sydney, Australia

Matthias Klapperstück Monash University, Melbourne, Australia

Karsten Klein Monash University, Melbourne, Australia; University of Sydney, Sydney, Australia; University of Konstanz, Konstanz, Germany

Torsten Wolfgang Kuhlen RWTH Aachen University, Aachen, Germany

Bongshin Lee Microsoft Research, Redmond, USA

Todd Margolis Qlik, Irvine, CA, USA

Kim Marriott Monash University, Melbourne, Australia

Jon McCormack Monash University, Melbourne, Australia

Thomas Morgan Monash University, Melbourne, Australia

Miguel A. Nacenta University of St Andrews, St Andrews, Scotland

Chris North Virginia Tech, Blacksburg, USA

Steffen Oeltze-Jafra University of Leipzig, Leipzig, Germany

Huamin Qu Hong Kong University of Science and Technology, Kowloon, Hong Kong

Guido Reina University of Stuttgart, Stuttgart, Germany

Nathalie Henry Riche Microsoft, Redmond, USA

Jonathan C. Roberts Bangor University, Bangor, UK

Gerik Scheuermann University of Leipzig, Leipzig, Germany

Dieter Schmalstieg Graz University of Technology, Graz, Austria

Falk Schreiber University of Konstanz, Konstanz, Germany; Monash University, Melbourne, Australia

Ross T. Smith University of South Australia, Adelaide, Australia

Björn Sommer Monash University, Melbourne, Australia; University of Konstanz, Konstanz, Germany

Wolfgang Stuerzlinger Simon Fraser University, Burnaby, Canada

Aurélien Tabard University Lyon, Lyon, France

Bruce H. Thomas University of South Australia, Adelaide, Australia

Gregory F. Welch University of Central Florida, Orlando, USA

Wesley Willett University of Calgary, Calgary, Canada