

Contents

| | |
|---|-------|
| Preface | xv |
| Why a New Book? | xv |
| Existing Books | xvi |
| Audience | xvii |
| Who's Who | xviii |
| Structure: What's in This Book | xviii |
| What's Not in This Book | xx |
| Acknowledgments | xx |
| 1 What's Vis, and Why Do It? | 1 |
| 1.1 The Big Picture | 1 |
| 1.2 Why Have a Human in the Loop? | 2 |
| 1.3 Why Have a Computer in the Loop? | 4 |
| 1.4 Why Use an External Representation? | 6 |
| 1.5 Why Depend on Vision? | 6 |
| 1.6 Why Show the Data in Detail? | 7 |
| 1.7 Why Use Interactivity? | 9 |
| 1.8 Why Is the Vis Idiom Design Space Huge? | 10 |
| 1.9 Why Focus on Tasks? | 11 |
| 1.10 Why Focus on Effectiveness? | 11 |
| 1.11 Why Are Most Designs Ineffective? | 12 |
| 1.12 Why Is Validation Difficult? | 14 |
| 1.13 Why Are There Resource Limitations? | 14 |
| 1.14 Why Analyze? | 16 |
| 1.15 Further Reading | 18 |
| 2 What: Data Abstraction | 20 |
| 2.1 The Big Picture | 21 |
| 2.2 Why Do Data Semantics and Types Matter? | 21 |
| 2.3 Data Types | 23 |
| 2.4 Dataset Types | 24 |
| 2.4.1 Tables | 25 |
| 2.4.2 Networks and Trees | 26 |
| 2.4.2.1 Trees | 27 |

| | | |
|---------|---|----|
| 2.4.3 | Fields | 27 |
| 2.4.3.1 | Spatial Fields | 28 |
| 2.4.3.2 | Grid Types | 29 |
| 2.4.4 | Geometry | 29 |
| 2.4.5 | Other Combinations | 30 |
| 2.4.6 | Dataset Availability | 31 |
| 2.5 | Attribute Types | 31 |
| 2.5.1 | Categorical | 32 |
| 2.5.2 | Ordered: Ordinal and Quantitative | 32 |
| 2.5.2.1 | Sequential versus Diverging | 33 |
| 2.5.2.2 | Cyclic | 33 |
| 2.5.3 | Hierarchical Attributes | 33 |
| 2.6 | Semantics | 34 |
| 2.6.1 | Key versus Value Semantics | 34 |
| 2.6.1.1 | Flat Tables | 34 |
| 2.6.1.2 | Multidimensional Tables | 36 |
| 2.6.1.3 | Fields | 37 |
| 2.6.1.4 | Scalar Fields | 37 |
| 2.6.1.5 | Vector Fields | 37 |
| 2.6.1.6 | Tensor Fields | 38 |
| 2.6.1.7 | Field Semantics | 38 |
| 2.6.2 | Temporal Semantics | 38 |
| 2.6.2.1 | Time-Varying Data | 39 |
| 2.7 | Further Reading | 40 |
| 3 | Why: Task Abstraction | 42 |
| 3.1 | The Big Picture | 43 |
| 3.2 | Why Analyze Tasks Abstractly? | 43 |
| 3.3 | Who: Designer or User | 44 |
| 3.4 | Actions | 45 |
| 3.4.1 | Analyze | 45 |
| 3.4.1.1 | Discover | 47 |
| 3.4.1.2 | Present | 47 |
| 3.4.1.3 | Enjoy | 48 |
| 3.4.2 | Produce | 49 |
| 3.4.2.1 | Annotate | 49 |
| 3.4.2.2 | Record | 49 |
| 3.4.2.3 | Derive | 50 |
| 3.4.3 | Search | 53 |
| 3.4.3.1 | Lookup | 53 |
| 3.4.3.2 | Locate | 53 |
| 3.4.3.3 | Browse | 53 |
| 3.4.3.4 | Explore | 54 |

| | | |
|---------|---|----|
| 3.4.4 | Query | 54 |
| 3.4.4.1 | Identify | 54 |
| 3.4.4.2 | Compare | 55 |
| 3.4.4.3 | Summarize | 55 |
| 3.5 | Targets | 55 |
| 3.6 | How: A Preview | 57 |
| 3.7 | Analyzing and Deriving: Examples | 59 |
| 3.7.1 | Comparing Two Idioms | 59 |
| 3.7.2 | Deriving One Attribute | 60 |
| 3.7.3 | Deriving Many New Attributes | 62 |
| 3.8 | Further Reading | 64 |
| 4 | Analysis: Four Levels for Validation | 66 |
| 4.1 | The Big Picture | 67 |
| 4.2 | Why Validate? | 67 |
| 4.3 | Four Levels of Design | 67 |
| 4.3.1 | Domain Situation | 69 |
| 4.3.2 | Task and Data Abstraction | 70 |
| 4.3.3 | Visual Encoding and Interaction Idiom | 71 |
| 4.3.4 | Algorithm | 72 |
| 4.4 | Angles of Attack | 73 |
| 4.5 | Threats to Validity | 74 |
| 4.6 | Validation Approaches | 75 |
| 4.6.1 | Domain Validation | 77 |
| 4.6.2 | Abstraction Validation | 78 |
| 4.6.3 | Idiom Validation | 78 |
| 4.6.4 | Algorithm Validation | 80 |
| 4.6.5 | Mismatches | 81 |
| 4.7 | Validation Examples | 81 |
| 4.7.1 | Genealogical Graphs | 81 |
| 4.7.2 | MatrixExplorer | 83 |
| 4.7.3 | Flow Maps | 85 |
| 4.7.4 | LiveRAC | 87 |
| 4.7.5 | LinLog | 89 |
| 4.7.6 | Sizing the Horizon | 90 |
| 4.8 | Further Reading | 91 |
| 5 | Marks and Channels | 94 |
| 5.1 | The Big Picture | 95 |
| 5.2 | Why Marks and Channels? | 95 |
| 5.3 | Defining Marks and Channels | 95 |
| 5.3.1 | Channel Types | 99 |
| 5.3.2 | Mark Types | 99 |

| | | |
|-------|--|-----|
| 5.4 | Using Marks and Channels | 99 |
| 5.4.1 | Expressiveness and Effectiveness | 100 |
| 5.4.2 | Channel Rankings | 101 |
| 5.5 | Channel Effectiveness | 103 |
| 5.5.1 | Accuracy | 103 |
| 5.5.2 | Discriminability | 106 |
| 5.5.3 | Separability | 106 |
| 5.5.4 | Popout | 109 |
| 5.5.5 | Grouping | 111 |
| 5.6 | Relative versus Absolute Judgements | 112 |
| 5.7 | Further Reading | 114 |
| 6 | Rules of Thumb | 116 |
| 6.1 | The Big Picture | 117 |
| 6.2 | Why and When to Follow Rules of Thumb? | 117 |
| 6.3 | No Unjustified 3D | 117 |
| 6.3.1 | The Power of the Plane | 118 |
| 6.3.2 | The Disparity of Depth | 118 |
| 6.3.3 | Occlusion Hides Information | 120 |
| 6.3.4 | Perspective Distortion Dangers | 121 |
| 6.3.5 | Other Depth Cues | 123 |
| 6.3.6 | Tilted Text Isn't Legible | 124 |
| 6.3.7 | Benefits of 3D: Shape Perception | 124 |
| 6.3.8 | Justification and Alternatives | 125 |
| | Example: Cluster–Calendar Time-Series Vis | 125 |
| | Example: Layer-Oriented Time-Series Vis | 128 |
| 6.3.9 | Empirical Evidence | 129 |
| 6.4 | No Unjustified 2D | 131 |
| 6.5 | Eyes Beat Memory | 131 |
| 6.5.1 | Memory and Attention | 132 |
| 6.5.2 | Animation versus Side-by-Side Views | 132 |
| 6.5.3 | Change Blindness | 133 |
| 6.6 | Resolution over Immersion | 134 |
| 6.7 | Overview First, Zoom and Filter, Details on Demand | 135 |
| 6.8 | Responsiveness Is Required | 137 |
| 6.8.1 | Visual Feedback | 138 |
| 6.8.2 | Latency and Interaction Design | 138 |
| 6.8.3 | Interactivity Costs | 140 |
| 6.9 | Get It Right in Black and White | 140 |
| 6.10 | Function First, Form Next | 140 |
| 6.11 | Further Reading | 141 |

| | | |
|-------|---|-----|
| 7 | Arrange Tables | 144 |
| 7.1 | The Big Picture | 145 |
| 7.2 | Why Arrange? | 145 |
| 7.3 | Arrange by Keys and Values | 145 |
| 7.4 | Express: Quantitative Values | 146 |
| | Example: Scatterplots | 146 |
| 7.5 | Separate, Order, and Align: Categorical Regions | 149 |
| 7.5.1 | List Alignment: One Key | 149 |
| | Example: Bar Charts | 150 |
| | Example: Stacked Bar Charts | 151 |
| | Example: Streamgraphs | 153 |
| | Example: Dot and Line Charts | 155 |
| 7.5.2 | Matrix Alignment: Two Keys | 157 |
| | Example: Cluster Heatmaps | 158 |
| | Example: Scatterplot Matrix | 160 |
| 7.5.3 | Volumetric Grid: Three Keys | 161 |
| 7.5.4 | Recursive Subdivision: Multiple Keys | 161 |
| 7.6 | Spatial Axis Orientation | 162 |
| 7.6.1 | Rectilinear Layouts | 162 |
| 7.6.2 | Parallel Layouts | 162 |
| | Example: Parallel Coordinates | 162 |
| 7.6.3 | Radial Layouts | 166 |
| | Example: Radial Bar Charts | 167 |
| | Example: Pie Charts | 168 |
| 7.7 | Spatial Layout Density | 171 |
| 7.7.1 | Dense | 172 |
| | Example: Dense Software Overviews | 172 |
| 7.7.2 | Space-Filling | 174 |
| 7.8 | Further Reading | 175 |
| 8 | Arrange Spatial Data | 178 |
| 8.1 | The Big Picture | 179 |
| 8.2 | Why Use Given? | 179 |
| 8.3 | Geometry | 180 |
| 8.3.1 | Geographic Data | 180 |
| | Example: Choropleth Maps | 181 |
| 8.3.2 | Other Derived Geometry | 182 |
| 8.4 | Scalar Fields: One Value | 182 |
| 8.4.1 | Isocontours | 183 |
| | Example: Topographic Terrain Maps | 183 |
| | Example: Flexible Isosurfaces | 185 |
| 8.4.2 | Direct Volume Rendering | 186 |
| | Example: Multidimensional Transfer Functions | 187 |

| | | |
|--------|--|-----|
| 8.5 | Vector Fields: Multiple Values | 189 |
| 8.5.1 | Flow Glyphs | 191 |
| 8.5.2 | Geometric Flow | 191 |
| | Example: Similarity-Clustered Streamlines | 192 |
| 8.5.3 | Texture Flow | 193 |
| 8.5.4 | Feature Flow | 193 |
| 8.6 | Tensor Fields: Many Values | 194 |
| | Example: Ellipsoid Tensor Glyphs | 194 |
| 8.7 | Further Reading | 197 |
| 9 | Arrange Networks and Trees | 200 |
| 9.1 | The Big Picture | 201 |
| 9.2 | Connection: Link Marks | 201 |
| | Example: Force-Directed Placement | 204 |
| | Example: sfdp | 207 |
| 9.3 | Matrix Views | 208 |
| | Example: Adjacency Matrix View | 208 |
| 9.4 | Costs and Benefits: Connection versus Matrix | 209 |
| 9.5 | Containment: Hierarchy Marks | 213 |
| | Example: Treemaps | 213 |
| | Example: GrouseFlocks | 215 |
| 9.6 | Further Reading | 216 |
| 10 | Map Color and Other Channels | 218 |
| 10.1 | The Big Picture | 219 |
| 10.2 | Color Theory | 219 |
| 10.2.1 | Color Vision | 219 |
| 10.2.2 | Color Spaces | 220 |
| 10.2.3 | Luminance, Saturation, and Hue | 223 |
| 10.2.4 | Transparency | 225 |
| 10.3 | Colormaps | 225 |
| 10.3.1 | Categorical Colormaps | 226 |
| 10.3.2 | Ordered Colormaps | 229 |
| 10.3.3 | Bivariate Colormaps | 234 |
| 10.3.4 | Colorblind-Safe Colormap Design | 235 |
| 10.4 | Other Channels | 236 |
| 10.4.1 | Size Channels | 236 |
| 10.4.2 | Angle Channel | 237 |
| 10.4.3 | Curvature Channel | 238 |
| 10.4.4 | Shape Channel | 238 |
| 10.4.5 | Motion Channels | 238 |
| 10.4.6 | Texture and Stippling | 239 |
| 10.5 | Further Reading | 240 |

| | |
|--|-----|
| 11 Manipulate View | 242 |
| 11.1 The Big Picture | 243 |
| 11.2 Why Change? | 244 |
| 11.3 Change View over Time | 244 |
| Example: LineUp | 246 |
| Example: Animated Transitions | 248 |
| 11.4 Select Elements | 249 |
| 11.4.1 Selection Design Choices | 250 |
| 11.4.2 Highlighting | 251 |
| Example: Context-Preserving Visual Links | 253 |
| 11.4.3 Selection Outcomes | 254 |
| 11.5 Navigate: Changing Viewpoint | 254 |
| 11.5.1 Geometric Zooming | 255 |
| 11.5.2 Semantic Zooming | 255 |
| 11.5.3 Constrained Navigation | 256 |
| 11.6 Navigate: Reducing Attributes | 258 |
| 11.6.1 Slice | 258 |
| Example: HyperSlice | 259 |
| 11.6.2 Cut | 260 |
| 11.6.3 Project | 261 |
| 11.7 Further Reading | 261 |
| 12 Facet into Multiple Views | 264 |
| 12.1 The Big Picture | 265 |
| 12.2 Why Facet? | 265 |
| 12.3 Juxtapose and Coordinate Views | 267 |
| 12.3.1 Share Encoding: Same/Different | 267 |
| Example: Exploratory Data Visualizer (EDV) | 268 |
| 12.3.2 Share Data: All, Subset, None | 269 |
| Example: Bird's-Eye Maps | 270 |
| Example: Multiform Overview–Detail Microarrays | 271 |
| Example: Cerebral | 274 |
| 12.3.3 Share Navigation: Synchronize | 276 |
| 12.3.4 Combinations | 276 |
| Example: Improvise | 277 |
| 12.3.5 Juxtapose Views | 278 |
| 12.4 Partition into Views | 279 |
| 12.4.1 Regions, Glyphs, and Views | 279 |
| 12.4.2 List Alignments | 281 |
| 12.4.3 Matrix Alignments | 282 |
| Example: Trellis | 282 |
| 12.4.4 Recursive Subdivision | 285 |
| 12.5 Superimpose Layers | 288 |

| | | |
|--------|--|-----|
| 12.5.1 | Visually Distinguishable Layers | 289 |
| 12.5.2 | Static Layers | 289 |
| | Example: Cartographic Layering | 289 |
| | Example: Superimposed Line Charts | 290 |
| | Example: Hierarchical Edge Bundles | 292 |
| 12.5.3 | Dynamic Layers | 294 |
| 12.6 | Further Reading | 295 |
| 13 | Reduce Items and Attributes | 298 |
| 13.1 | The Big Picture | 299 |
| 13.2 | Why Reduce? | 299 |
| 13.3 | Filter | 300 |
| 13.3.1 | Item Filtering | 301 |
| | Example: FilmFinder | 301 |
| 13.3.2 | Attribute Filtering | 303 |
| | Example: DOSFA | 304 |
| 13.4 | Aggregate | 305 |
| 13.4.1 | Item Aggregation | 305 |
| | Example: Histograms | 306 |
| | Example: Continuous Scatterplots | 307 |
| | Example: Boxplot Charts | 308 |
| | Example: SolarPlot | 310 |
| | Example: Hierarchical Parallel Coordinates | 311 |
| 13.4.2 | Spatial Aggregation | 313 |
| | Example: Geographically Weighted Boxplots | 313 |
| 13.4.3 | Attribute Aggregation: Dimensionality Reduction | 315 |
| | 13.4.3.1 Why and When to Use DR? | 316 |
| | Example: Dimensionality Reduction for Document Collections | 316 |
| | 13.4.3.2 How to Show DR Data? | 319 |
| 13.5 | Further Reading | 320 |
| 14 | Embed: Focus+Context | 322 |
| 14.1 | The Big Picture | 323 |
| 14.2 | Why Embed? | 323 |
| 14.3 | Elide | 324 |
| | Example: DOITrees Revisited | 325 |
| 14.4 | Superimpose | 326 |
| | Example: Toolglass and Magic Lenses | 326 |
| 14.5 | Distort | 327 |
| | Example: 3D Perspective | 327 |
| | Example: Fisheye Lens | 328 |
| | Example: Hyperbolic Geometry | 329 |

| | |
|---|-----|
| Example: Stretch and Squish Navigation | 331 |
| Example: Nonlinear Magnification Fields | 333 |
| 14.6 Costs and Benefits: Distortion | 334 |
| 14.7 Further Reading | 337 |
| 15 Analysis Case Studies | 340 |
| 15.1 The Big Picture | 341 |
| 15.2 Why Analyze Case Studies? | 341 |
| 15.3 Graph-Theoretic Scagnostics | 342 |
| 15.4 VisDB | 347 |
| 15.5 Hierarchical Clustering Explorer | 351 |
| 15.6 PivotGraph | 355 |
| 15.7 InterRing | 358 |
| 15.8 Constellation | 360 |
| 15.9 Further Reading | 366 |
| Figure Credits | 369 |
| Bibliography | 375 |
| Idiom and System Examples Index | 397 |
| Concept Index | 399 |