

2nd Edition

# Data Visualisation

A Handbook for Data Driven Design



Andy Kirk



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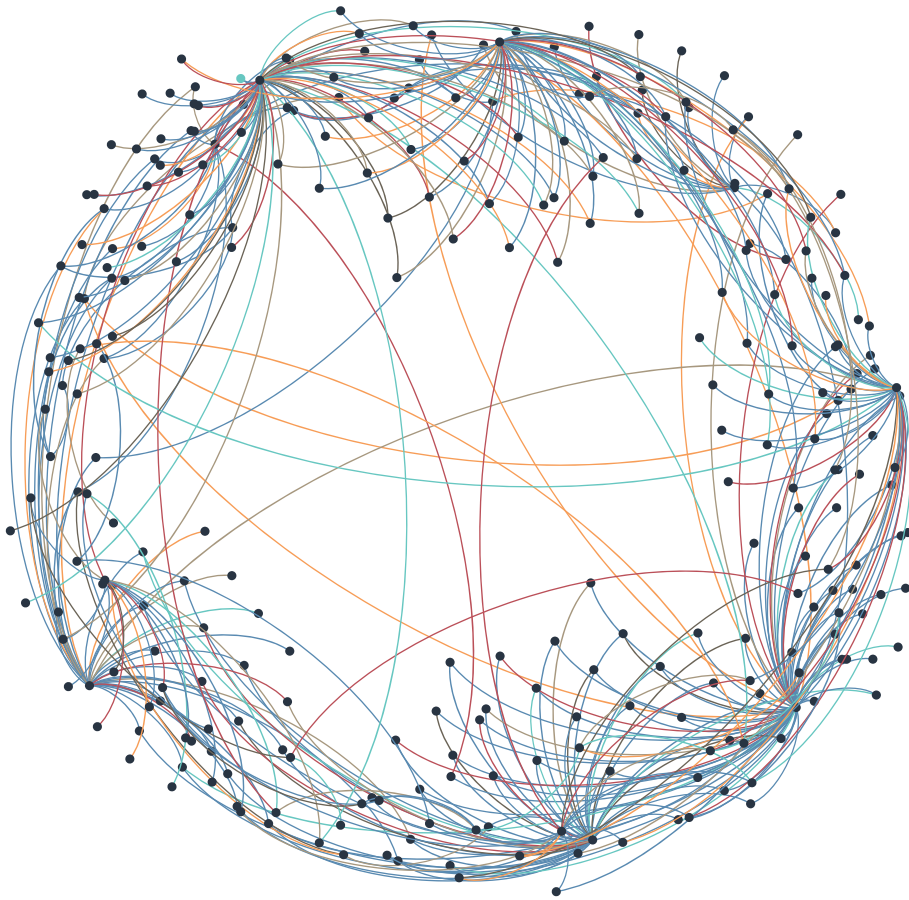
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# Acknowledgements

I could not have written this book without the unwavering support of my wonderful wife, Ellie, and my family. The book is dedicated to my inspirational Dad who sadly passed away before its publication. I want to acknowledge the contributions of the thousands of data visualisation practitioners who have created such a wealth of exceptional design work and smart writing. I have been devouring this for over a decade now and I am constantly inspired by the talents and minds behind it all. I also want to express my gratitude to the people and organisations who have granted me permission to reference and showcase their visualisation work in this book. Sincere thanks to the many people at Sage who have played a role in making this book grow from the first proposal and now to a second edition. Finally, to you the readers, I am hugely thankful that you chose to invest in this book. I hope it helps you in your journey to learning about this super subject.





# About the Author

Andy Kirk is a freelance data visualisation specialist based in Yorkshire, UK. He is a visualisation design consultant, training provider, teacher, author, speaker, researcher and editor of the award-winning website [visualisingdata.com](http://visualisingdata.com).

After graduating from Lancaster University in 1999 with a BSc (hons) in Operational Research, Andy's working life began with a variety of business analysis and information management roles at organisations including CIS Insurance, West Yorkshire Police and the University of Leeds.

He discovered *data visualisation* in early 2007, when it was lurking somewhat on the fringes of the Web. Fortunately, the timing of this discovery coincided with his shaping of his Master's (MA) degree research proposal, a self-directed research programme that gave him the opportunity to unlock and secure his passion for the subject.

He launched [visualisingdata.com](http://visualisingdata.com) to continue the process of discovery and to chart the course of the increasing popularity of the subject. Over time, this award-winning site has grown to become a popular reference for followers of the field, offering contemporary discourse, design techniques and vast collections of visualisation examples and resources.

Andy became a freelance professional in 2011. Since then he has been fortunate to work with a diverse range of clients across the world, including organisations such as Google, CERN, Electronic Arts, the EU Council, Hershey and McKinsey. At the time of publication, he will have delivered over 270 public and private training events in 25 different countries, reaching more than 6000 delegates. Alongside his busy training schedule, Andy also provides design consultancy, his primary client being the Arsenal FC Performance Team, since 2015.

In addition to his commercial activities, he maintains regular engagements in academia. Between 2014 and 2015 he was an external consultant on a research project called 'Seeing Data', funded by the Arts & Humanities Research Council and hosted by the University of Sheffield. This study explored the issues of data visualisation literacy among the general public and, inter alia, helped to shape an understanding of the human factors that affect visualisation literacy and the effectiveness of design.

Andy joined the highly respected Maryland Institute College of Art (MICA) as a visiting lecturer in 2013 teaching a module on the Information Visualisation Master's Programme through to 2017. From January 2016, he taught a data visualisation module as part of the MSc in Business Analytics at the Imperial College Business School in London through to 2018. As of May 2019, Andy has started teaching at University College London (UCL).



# Discover Your Textbook's Online Resources

Want more support around understanding and creating data visualisations? Andy Kirk is here to help, offline and on!

Hosted by the author and with resources organized by chapter, the supporting website for this book has everything you need to explore, practice, and hone your data visualisation skills.

- **Explore the field:** expand your knowledge and reinforce your learning about working with data through libraries of further reading, references, and tutorials.
- **Try this yourself:** revise, reflect, and refine your skill and understanding about the challenges of working with data through practical exercises.
- **See data visualisation in action:** get to grips with the nuances and intricacies of working with data in the real world by navigating instalments of the narrative case study and seeing an additional extended example of data visualisation in practice. Follow along with Andy's video diary of the process and get direct insight into his thought processes, challenges, mistakes, and decisions along the way.
- **Chartmaker directory:** access crowd-sourced guidance that aims to answer the crucial question 'which tools make which charts?' with this growing directory of examples and technical solutions for chart building.

Ready to learn more? Go beyond the book and dive deeper into data visualisation via the rest of Andy's website ([www.visualisingdata.com](http://www.visualisingdata.com)), which contains **data visualisation tools and software**, links to additional influential further reading, and a **blog with monthly collections** of the best data visualisation examples and resources each month.



# Introduction

The primary challenge one faces when writing a book about data visualisation is to determine what to leave in and what to leave out. Data visualisation is a big subject. There is no single book to rule it all because there is no one book that can truly cover it all. Each and every one of the topics covered by the chapters in this book could (and, in several cases, do) exist as books in their own right.

The secondary challenge when writing a book about data visualisation is to decide how to weave the content together. Data visualisation is not rocket science; it is not an especially complicated discipline, though it can be when working on sophisticated topics and with advanced applications. It is, however, a complex subject. There are lots of things to think about, many things to do and, of course, things that will need making. Creative and journalistic sensibilities need to blend harmoniously with analytical and scientific judgement. In one moment, you might be checking the statistical rigour of an intricate calculation, in the next deciding which shade of orange most strikingly contrasts with a vibrant blue. The complexity of data visualisation manifests in how the myriad small ingredients interact, influence and intersect to form a whole.

The decisions I have made when formulating this book's content have been shaped by my own process of learning. I have been researching, writing about and practising data visualisation for over a decade. I believe you only truly learn about your own knowledge of a subject when you have to explain it and teach it to others. To this extent I have been fortunate to have had extensive experience designing and delivering commercial training as well as academic teaching.

I believe this book offers an effective and proven pedagogy that successfully translates the complexities of this subject in a form that is fundamentally useful. I feel well placed to bridge the gap between the *everyday* practitioners, who might identify themselves as beginners, and the superstar talents expanding the potential of data visualisation. I am not going to claim to belong to the latter cohort, but I have certainly been a novice, taking tentative early steps into this world. Most of my working hours are spent helping others start their journey. I know what I would have valued when I started out in this field and this helps inform how I now pass this on to others in the same position I was several years ago.

There is a large and growing library of fantastic books offering different theoretical and practical viewpoints on this subject. My aim is to add value to this existing collection by approaching the subject through the perspective of process. I believe the path to mastering data visualisation is achieved by making better decisions: namely, effective choices, efficiently made. I will help you understand what decisions need to be made and give you the confidence to make the right choices. Before moving on to discuss the book's intended audience, here are its key aims:

- To **challenge** your existing approaches to creating and consuming visualisations. I will challenge your beliefs about what you consider to be effective or ineffective visualisation. I will encourage you to eliminate arbitrary choices from your thinking, rely less on taste and instinct, and become more reasoned in your judgements.
- To **enlighten** you I will increase your awareness of the possible approaches to visualising data. This book will broaden your visual vocabulary, giving you a wider and more sophisticated understanding of the contemporary techniques used to express your data visually.
- To **equip** is to provide you with robust tactics for managing your way through the myriad options that exist in data visualisation. To help you overcome the burden of choice, an adaptable framework is offered to help you think for yourself, rather than relying on inflexible rules and narrow instruction.
- To **inspire** is to open the door to a subject that will stimulate you to elevate your ambition and broaden your confidence. Developing competency in data visualisation will take time and will need more than just reading this book. It will require a commitment to embrace the obstacles that each new data visualisation opportunity poses through practice. It will require persistence to learn, apply, reflect and improve.

## Who Is This Book Aimed At?

Anyone who has reason to use quantitative and qualitative methods in their professional or academic duties will need to grasp the demands of data visualisation. Whether this is a large part of your duties or just a small part, this book will support your needs.

The primary intended audiences are undergraduates, postgraduates and early-career researchers. Although aimed at those in the social sciences, the content will be relevant to readers from across the spectrum of arts and humanities right through to the natural sciences.

This book is intended to offer an accessible route for novices to start their data visualisation learning journey and, for those already familiar with the basics, the content will hopefully contribute to refining their capabilities. It is not aimed at experienced or established visualisation practitioners, though there may be some new perspectives to enrich their thinking: some content will reinforce existing knowledge, other content might challenge their convictions.

The people who are active in this field come from all backgrounds. Outside academia, data visualisation has reached the mainstream consciousness in professional and commercial contexts. An increasing number of professionals and organisations, across all industry types and sizes, are embracing the importance of getting more value from their data and doing more with it, for both internal and external benefit. You might be a market researcher, a librarian or a data analyst looking to enhance your data capabilities. Perhaps you are a skilled graphic designer or web developer looking to take your portfolio of work into a more data-driven direction. Maybe you are in a managerial position and though not directly involved in the creation of visualisation work, you might wish to improve the sophistication of the language you coordinate or commission others who are. Everyone needs the lens and vocabulary to evaluate work effectively.

Data visualisation is a genuinely multidisciplinary discipline. Nobody arrives fully formed with all constituent capabilities. The pre-existing knowledge, skills or experiences which, I think, reflect the traits needed to get the most out of this book would include:

- Strong numeracy is necessary as well as a familiarity with basic **statistics**.
- While it is reasonable to assume limited prior knowledge of data visualisation, there should be a strong **desire** to want to learn it. The demands of learning a craft like this take time and effort; the capabilities will need nurturing through ongoing learning and practice. They are not going to be achieved overnight or acquired alone from reading this book. Any book that claims to be able magically to inject mastery through just reading it cover to cover is over-promising and likely to under-deliver.
- The best data visualisers possess inherent **curiosity**. You should be the type of person who is naturally disposed to question the world around them. Your instinct for discovering and sharing answers will be at the heart of this activity.
- There are no expectations of your having any prior familiarity with **design** principles, but an appetite to embrace some of the creative aspects presented in this book will heighten the impact of your work. Time to unleash that suppressed imagination!
- If you *are* somebody fortunate to possess already a strong creative flair, this book will guide you through when and crucially when *not* to tap into this sensibility. You should be willing to increase the rigour of your **analytical** decision making and be prepared to have your creative thinking informed more fundamentally by data rather than just instinct.
- No particular **technical** skills are required to get value from this book, as I will explain shortly. But you will ideally have some basic knowledge of spreadsheets and experience of working with data irrespective of which particular tool.

This is a portable practice involving techniques that are subject-matter agnostic. Throughout this book you will see a broad array of examples from different industries covering many different topics. Do not be deterred by any example being about a subject different to your own area of interest. Look beyond the subject and you will see analytical and design choices that are just as applicable to you and your work: a line chart showing political forecasts involves the same thought process as would a line chart showing stock prices changing or average global temperatures rising. A line chart is a line chart, regardless of the subject matter.

The type of data you are working with is the only legitimate restriction to the design methods you might employ, not your subject and certainly not traditions in your subject. ‘Waterfall charts are only for people in finance’, ‘maps are only for cartographers’, ‘Sankey diagrams are only for engineers’. Enter this subject with an open mind, forget what you believe or have been told is the *normal* approach, and your capabilities will be expanded.

Data visualisation is an entirely global community, not the preserve of any geographic region. Although the English language dominates written discourse, the interest in the subject and work created from studios through to graphics teams originates everywhere. There are cultural influences and different flavours in design sensibility around the world which enrich the field but, otherwise, it is a practice common and accessible to all.



## Finding the Balance

### Handbook vs Manual

The description of this book as a ‘handbook’ positions it as distinct from a tutorial-based manual. It aims to offer conceptual and practical guidance, rather than technical instruction. Think of it more as a guidebook for a tourist visiting a city than an instruction manual for how to fix a washing machine.

Apart from a small proportion of visualisation work that is created manually, the reliance on technology to create visualisation work is an inseparable necessity. For many beginners in visualisation there is an understandable appetite for step-by-step tutorials that help them immediately to implement their newly acquired techniques.

However, writing about data visualisation through the lens of selected tools is hard, given the diversity of technical options that exist in the context of such varied skills, access and needs. The visualisation technology space is characterised by flux. New tools are constantly emerging to supplement the many that already exist. Some are proprietary, others are open source; some are easier to learn but do not offer much functionality; others do offer rich potential but require a great deal of foundation understanding before you even accomplish your first bar chart. Some tools evolve to keep up with current techniques; they are well supported by vendors and have thriving user communities, others less so. Some will exist as long-term options whereas others depreciate. Many have briefly burnt brightly but quickly become obsolete or have been swallowed up by others higher up the food chain. Tools come and go but the craft remains.

There is a role for all book types and a need for more than one to acquire true competency in a subject. Different people want different sources of insight at different stages in their development. If you *are* seeking a text that provides instructive tutorials, you will learn from this how to accomplish technical developments in a given technology. However, if you *only* read tutorial-based books, you will likely fall short in the fundamental critical thinking that will be needed to harness data visualisation as a skill.

I believe a practical, rather than technical, text focusing on the underlying craft of data visualisation through a tool-agnostic approach offers the most effective guide to help people learn this subject.

The content of this book will be relevant to readers regardless of their technical knowledge and experience. The focus will be to take your critical thinking towards a detailed, fully reasoned design specification – a declaration of intent of what you want to develop. Think of the distinction as similar to that between architecture (design specification) and engineering (design execution).

There is a section in Chapter 3 that describes the influence technology has on your work and the places it will shape your ambitions. Furthermore, among the digital resources offered online are further profiles of applications, tools and libraries in common use in the field today and a vast directory of resources offering instructive tutorials. These will help you to apply technically the critical capabilities you acquire throughout this book.

## Useful vs Beautiful

Another important distinction to make is that this book is not intended to be seen as a beauty pageant. I love flicking through glossy ‘coffee table’ books as they offer great inspiration, but often lack substance beyond the evident beauty. This book serves a different purpose to that. I believe, for a beginner or relative beginner, the most valuable inspiration comes more from understanding the thinking behind some of the amazing works encountered today, learning about the decisions that led to their conceptual development.

My desire is to make this the most *useful* text available, a reference that will spend more time on your desk than on your bookshelf. To be useful is to be used. I want the pages to be dog-eared. I want to see scribbles and annotated notes made across its pages and key passages underlined. I want to see sticky labels peering out above identified pages of note. I want to see creases where pages have been folded back or a double-page spread that has been weighed down to keep it open. It will be an elegantly presented and packaged book, but it should not be something that invites you to look but not touch.

## Pragmatic vs Theoretical

The content of this book has been formed through years of absorbing knowledge from as many books as my shelves can hold, generations of academic work, endless web articles, hundreds of conference talks, personal interactions with the great and the good of the field, and lots and lots of practice. More accurately, lots and lots of mistakes. What I present here is a pragmatic distillation of what I have learned and feel others will benefit from learning too.

It is not a deeply academic or theoretical book. Experienced or especially curious practitioners may have a desire for deeper theoretical discourse, but that is beyond the intent of this particular text. You have to draw a line somewhere to determine the depth you can reasonably explore about a given topic. Take the science of visual perception, for example, arguably the subject’s foundation. There is no value in replicating or attempting to better what has already been covered by other books in greater quality than I could achieve.

An important reason for giving greater weight to pragmatism is because of the inherent imperfections of this subject. Although there is so much important empirical thinking in this subject, the practical application can sometimes fail to translate beyond the somewhat artificial context of a research study. Real-world circumstances and the strong influence of human factors can easily distort the significance of otherwise robust concepts.

Critical thinking will be the watchword, equipping you with the independence of thought to decide rationally for yourself which solutions best fit your context, your data, your message and your audience. To accomplish this, you will need to develop an appreciation of all the options available to you (the different things you *could* do) and a reliable approach for critically determining what choices you should make (the things you *will* do and *why*).

## Contemporary vs Historical

I have huge respect for the ancestors of this field, the dominant names who, despite primitive means, pioneered new concepts in the visual display of statistics to shape the foundations of the field being practised today. The field's lineage is decorated by pioneers such as William Playfair, W. E. B. Du Bois, Florence Nightingale and John Snow, to name but a few. To many beginners in the field, the historical context of this subject is of huge interest. However, this kind of content has already been covered by plenty of other book and article authors.

I do not want to bloat this book with the unnecessary reprising of topics that have been covered at length elsewhere. I am not going to spend time attempting to enlighten you about how we live in the age of 'Big Data' and how occupations related to data are or will be the 'sexiest jobs' of our time. The former is no longer news, the latter claim emerged from a single source. There is more valuable and useful content I want you to focus your time on.

The subject matter, the ideas and the practices presented here will hopefully not date a great deal. Of course, many of the graphic examples included in the book will be surpassed by newer work demonstrating similar concepts as the field continues to develop. However, their worth as exhibits of a particular perspective covered in the text should prove timeless. As time passes there will be new techniques, new concepts and new, empirically evidenced rules. There will be new thought-leaders, new sources of reference and new visualisers to draw insight from. Things that prove a manual burden now may become seamlessly automated in the near future. That is the nature of a fast-growing field.

## Analysis vs Communication

A further distinction to make concerns the subtle but critical difference between visualisation used for analysing data and visualisation used for communicating data.

Before a visualiser can confidently decide what to communicate to others, he or she needs to have developed an intimate understanding of the qualities and potential of the data. In certain contexts, this might only be achieved through exploratory data analysis. Here, the visualiser and the viewer are the same person. Through visual exploration, interrogations of the data can be conducted to learn about its qualities and to unearth confirmatory or enlightening discoveries about what insights exist.

Visualisation for analysis is part of the journey towards creating visualisation for communication, but the techniques used for visual analysis do not have to be visually polished or necessarily appealing. They are only serving the purpose of helping you truly to learn about your data. When a data visualisation is being created to communicate to others, many careful considerations come into play about the requirements and interests of the intended audience. This influences many design decisions that do not exist alone with visual analysis.

For the scope of this book the content is weighted more towards methods and concerns about communicating data visually to others. If your role is concerned more with techniques for

exploratory analysis rather than visual communication, you will likely require a deeper treatment of the topic than this book can reasonably offer.

Another matter to touch on here concerns the coverage of statistics, or lack thereof. For many people, statistics can be a difficult topic to grasp. Even for those who are relatively numerate and comfortable working with simple statistical methods, it is quite easy to become rusty without frequent practice. The fear of making errors with intricate statistical calculations depresses confidence and a vicious circle begins.

You cannot avoid the need to use *some* statistical techniques if you are going to work with data. I will describe some of the most relevant statistical techniques in Chapter 4, at the point in your thinking where they are most applicable. However, I do believe the range and level of statistical techniques *most* people will need to employ on *most* of their visualisation tasks can be overstated. I know there will be exceptions, and a significant minority will be exposed to requiring advanced statistical thinking in their work.

It all depends, of course. In my experience, however, the majority of data visualisation challenges will generally involve relatively straightforward *univariate* and *bivariate* statistical techniques to describe data. Univariate techniques help you to understand the shape, size and range of a single variable of data, such as determining the minimum, maximum and average height of a group of people. Bivariate techniques are used to observe possible relationships between two different variables. For example, you might look at the relationship between gross domestic product and medal success for countries competing at the Olympics. You may also encounter visualisation challenges that require a basic understanding of probabilities to assist with forecasting risk or modelling uncertainty.

The more advanced applications of statistics will be required when working with larger complicated datasets, where *multivariate* techniques are employed simultaneously to model the significance of relationships between multiple variables. Above and beyond that, you are moving towards advanced statistical modelling and algorithm design.

Though it may seem unsatisfactory to offer little coverage of this topic, there is no value in reinventing the wheel. There are hundreds of existing books better placed to offer the depth you might need. That statistics is such a prolific and vast field in itself further demonstrates how deeply multidisciplinary a field visualisation truly is.

## Chapter Contents

The book is organised into three main parts (A, B and C) comprising ten chapters and an Epilogue. Each chapter opens with a preview of the content to be covered and closes with a summary of the most salient learning points to emerge. There are collections of further resources available online to substantiate the learning from each chapter.

For most readers, especially beginners, it is recommended that you start from the beginning and proceed through each chapter as presented. For those setting out to begin working on their own visualisation, you might jump straight into Chapters 2–5 to ensure you are fully prepared

for some of the important preparatory activities you need to accomplish before moving on to look at developing your design solution. For those with more experience and/or prior exposure to this subject, who are perhaps looking to fine-tune specific aspects of their design skills, most of your interest will lie in Part C, comprising Chapters 6–10. For readers who just want to dip in and out of specific topic areas, although each chapter builds sequentially from the preceding ones, they can all be read in isolation. Follow any sequence that satisfies your needs. The coloured tabs on the outer edge will provide quick visual navigation through the distinct parts and chapters within.

## Part A: Foundations

Part A introduces some important foundational understanding about data visualisation as a subject area and as an activity. The contents of the first two chapters give shape to the coverage across the rest of the book.

**Chapter 1** ‘Defining Data Visualisation’ will be the logical starting point for those who are new to the field, providing a definition for the subject and exploring some of the tensions that enrich this subject. The second section explains some of the distinctions and overlaps with other related disciplines. If you already know what data visualisation is about, you might choose to pass on this; it does, though, help frame many of the discussions elsewhere.

**Chapter 2** ‘The Visualisation Design Process’ introduces the value of following a design process, the sequence of activities around which the book’s contents in Parts B and C are organised. It explains what is involved and offers some useful tips to help you seamlessly adopt this approach. Where the process offers organisation and efficiency, design principles ensure effectiveness. The second section will describe what separates the good from the bad in visualisation design, building up your convictions to help with your upcoming decision making.

## Part B: The Hidden Thinking

Part B profiles the first three stages of the data visualisation design process. These are the hidden preparatory stages that will significantly influence the path you take towards an eventual solution.

**Chapter 3** ‘Formulating Your Brief’ covers the opening tasks involved in initiating, defining and planning the requirements of your work. The first section looks at issues around context, specifically about the importance of defining curiosity and identifying the circumstances that will shape your project. The second section considers the vision of your work, looking at what purpose it intends to serve and how you might creatively define the type of work you will need to pursue. Finally, a short section looks at the value of harnessing initial ideas.

**Chapter 4** ‘Working With Data’ commences your practical involvement with your data, stepping through the four distinct steps that acquaint you with the potential of your

critical raw material. Data acquisition outlines the different origins of and methods for obtaining your data. Data examination profiles the different characteristics that define the type, extent and condition of your data. Data transformation builds on your examination work to find ways of modifying and enhancing your data to prepare it for use. Finally, data exploration discusses methods for discovering more about the qualities and insights hidden away in your data.

**Chapter 5** ‘Establishing Your Editorial Thinking’ reflects on the possibilities offered by your data and explains the importance of committing to an editorial path. The chapter opens with a definition about the influence of editorial thinking, using two case studies to explain how editorial definitions influence design choices later in the process.

## Part C: Developing Your Design Solution

Part C represents the main part of this book and covers the five distinct layers of the data visualisation anatomy. They are presented in separate chapters to help organise your thinking and to avoid being overwhelmed by the detailed options that exist. However, they are ultimately interrelated matters and the chapter sequencing across this part is carefully arranged to support this. Each chapter follows a similar structure, opening with an array of different possible design options and supplemented by guidance on the factors that will influence your choices. Initially, you will need to make decisions about what elements to include around data representation (charts), interactivity and annotation. You will then complete your thinking about the appearance of these elements, through colour and composition.

**Chapter 6** ‘Data Representation’ introduces the act of visual encoding and then expands on this to provide a detailed profile of 49 distinct chart types to help broaden your visual vocabulary. The chapter closes with a run through the key factors that will influence the suitability of your data representation choices.

**Chapter 7** ‘Interactivity’ introduces the potential value of incorporating interactive features in your work, profiling a wide range of options – such as filtering, highlighting and animating – that will enable users to interrogate and control a visualisation. The chapter closes with the main considerations that will influence your selection of interactive features.

**Chapter 8** ‘Annotation’ describes the importance of providing useful assistance to your viewers, including headings, chart apparatus, and labels. The chapter closes with a look at which factors will inform the choices you make.

**Chapter 9** ‘Colour’ commences with an overview of different colour models. This provides the basis for understanding the different ways of applying colour to facilitate data legibility and deliver functional decoration. Once again, having introduced the options, we will look at how you arrive at appropriate choices.

**Chapter 10** ‘Composition’ explores the final element of developing your design solution concerning how you organise the placement and sizing of all your visual elements within the space you have to work. Looking at matters of layout, arrangement and chart sizing, we will then wrap up this topic with a discussion about how to make your decisions.