

A Hands-On Introduction to Data Science



This book introduces the field of data science in a practical and accessible manner, using a hands-on approach that assumes no prior knowledge of the subject. The foundational ideas and techniques of data science are provided independently from technology, allowing students to easily develop a firm understanding of the subject without a strong technical background, as well as being presented with material that will have continual relevance even after tools and technologies change. Using popular data science tools such as Python and R, the book offers many examples of real-life applications, with practice ranging from small to big data. A suite of online material for both instructors and students provides a strong supplement to the book, including datasets, chapter slides, solutions, sample exams, and curriculum suggestions. This entry-level textbook is ideally suited to readers from a range of disciplines wishing to build a practical, working knowledge of data science.

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Sophie, Zoe, and Sarah – for adding colors and
curiosity back to doing science and living life!

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Preface

Data science is one of the fastest-growing disciplines at the university level. We see more job postings that require training in data science, more academic appointments in the field, and more courses offered, both online and in traditional settings. It could be argued that data science is nothing novel, but just statistics through a different lens. What matters is that we are living in an era in which the kind of problems that could be solved using data are driving a huge wave of innovations in various industries – from healthcare to education, and from finance to policy-making. More importantly, data and data analysis are playing an increasingly large role in our day-to-day life, including in our democracy. Thus, knowing the basics of data and data analysis has become a fundamental skill that everyone needs, even if they do not want to pursue a degree in computer science, statistics, or data science. Recognizing this, many educational institutions have started developing and offering not just degrees and majors in the field but also minors and certificates in data science that are geared toward students who may not become data scientists but could still benefit from data literacy skills in the same way every student learns basic reading, writing, and comprehension skills.

This book is not just for data science majors but also for those who want to develop their data literacy. It is organized in a way that provides a very easy entry for almost anyone to become introduced to data science, but it also has enough fuel to take one from that beginning stage to a place where they feel comfortable obtaining and processing data for deriving important insights. In addition to providing basics of data and data processing, the book teaches standard tools and techniques. It also examines implications of the use of data in areas such as privacy, ethics, and fairness. Finally, as the name suggests, this text is meant to provide a hands-on introduction to these topics. Almost everything presented in the book is accompanied by examples and exercises that one could try – sometimes by hand and other times using the tools taught here. In teaching these topics myself, I have found this to be a very effective method.

The remainder of this preface explains how this book is organized, how it could be used for fulfilling various teaching needs, and what specific requirements a student needs to meet to make the most out of it.

Requirements and Expectations

This book is intended for advanced undergraduates or graduate students in information science, computer science, business, education, psychology, sociology, and related fields

who are interested in data science. It is not meant to provide in-depth treatment of any programming language, tool, or platform. Similarly, while the book covers topics such as machine learning and data mining, it is not structured to give detailed theoretical instruction on them; rather, these topics are covered in the context of applying them to solving various data problems with hands-on exercises.

The book assumes very little to no prior exposure to programming or technology. It does, however, expect the student to be comfortable with computational thinking (see Chapter 1) and the basics of statistics (covered in Chapter 3). The student should also have general computer literacy, including skills to download, install, and configure software, do file operations, and use online resources. Each chapter lists specific requirements and expectations, many of which can be met by going over some other parts of the book (usually an earlier chapter or an appendix).

Almost all the tools and software used in this book are free. There is no requirement of a specific operating system or computer architecture, but it is assumed that the student has a relatively modern computer with reasonable storage, memory, and processing power. In addition, a reliable and preferably high-speed Internet connection is required for several parts of this book.

Structure of the Book

The book is organized in four parts. Part I includes three chapters that serve as the foundations of data science. Chapter 1 introduces the field of data science, along with various applications. It also points out important differences and similarities with related fields of computer science, statistics, and information science. Chapter 2 describes the nature and structure of data as we encounter today. It initiates the student about data formats, storage, and retrieval infrastructures. Chapter 3 introduces several important techniques for data science. These techniques stem primarily from statistics and include correlation analysis, regression, and introduction to data analytics.

Part II of this book includes chapters to introduce various tools and platforms such as UNIX (Chapter 4), Python (Chapter 5), R (Chapter 6), and MySQL (Chapter 7). It is important to keep in mind that, since this is not a programming or database book, the objective here is not to go systematically into various parts of these tools. Rather, we focus on learning the basics and the relevant aspects of these tools to be able to solve various data problems. These chapters therefore are organized around addressing various data-driven problems. In the chapters covering Python and R, we also introduce basic machine learning.

But machine learning is a crucial topic for data science that cannot be treated just as an afterthought, which is why Part III of this book is devoted to it. Specifically, Chapter 8 provides a more formal introduction to machine learning and includes a few techniques that are basic and broadly applicable at the same time. Chapter 9 describes in some depth supervised learning methods, and Chapter 10 presents unsupervised learning. It should be noted that, since this book is focused on data science and not core computer science or mathematics, we skip much of the underlying math and formal structuring while discussing

and applying machine learning techniques. The chapters in Part III, however, do present machine learning methods and techniques using adequate math in order to discuss the theories and intuitions behind them in detail.

Finally, Part IV of this book takes the techniques from Part I, as well as the tools from Parts II and III to start applying them to problems of real-life significance. In Chapter 11, we take this opportunity by applying various data science techniques to several real-life problems, including those involving social media, finance, and social good. Finally, Chapter 12 provides additional coverage into data collection, experimentation, and evaluation.

The book is full of extra material that either adds more value and knowledge to your existing data science theories and practices, or provides broader and deeper treatment of some of the topics. Throughout the book, there are several FYI boxes that provide important and relevant information without interrupting the flow of the text, allowing the student to be aware of various issues such as privacy, ethics, and fairness without being overwhelmed by them. The appendices of this book provide quick reference to various formulations relating to differential calculus and probability, as well as helpful pointers and instructions for installing and configuring various tools used in the book. For those interested in using cloud-based platforms and tools, there is also an appendix that shows how to sign up, configure, and use them. Another appendix provides listing of various sources for obtaining small to large datasets for more practice and even participate in data challenges to win some cool prizes and recognition. There is also an appendix that provides helpful information related to data science jobs in various fields and what skills one should have to target those calls. Finally, a couple of appendices introduce the ideas of data ethics and data science for social good to inspire you to be a responsible and socially aware *data citizen*.

The book also has an online appendix (OA), accessible through the book's website at www.cambridge.org/shah, which is regularly updated to reflect any changes in data and other resources. The primary purpose for this online appendix is to provide you with the most current and updated datasets or links to datasets that you can download and use in the dozens of examples and try-it-yourself exercises in the chapters, as well as data problems at the end of the chapters. Look for the  icon at various places that inform you that you need to find the needed resource from OA. In the description of that exercise, you will see the specific number (e.g., OA 3.2) that tells you where exactly you should go in the online appendix.

Using This Book in Teaching

The book is quite deliberately organized around teaching data science to beginner computer science (CS) students or intermediate to advanced non-CS students. The book is modular, making it easier for both students and teachers to cover topics to the desired depth. This makes it quite suitable for the book to be used as a main reference book or textbook for

a data science curriculum. The following is a suggested curriculum path in data science using this book. It contains five courses, each lasting a semester or a quarter.

- Introduction to data science: Chapters 1 and 2, with some elements from Part II as needed.
- Data analytics: Chapter 3, with some elements from Part II as needed.
- Problem solving with data or programming for data science: Chapters 4–7.
- Machine learning for data science: Chapters 8–10.
- Research methods for data science: Chapter 12, with appropriate elements from Chapter 3 and Part II.

At the website for this book is a Resources tab with a section labeled “For Instructors.” This section contains sample syllabi for various courses that could be taught using this book, PowerPoint slides for each chapter, and other useful resources such as sample midterm and final exams. These resources make it easier for someone teaching this course for the first time to adapt the text as needed for his or her own data science curriculum.

Each chapter also has several conceptual questions and hands-on problems. The conceptual questions could be used in either in-class discussions, for homework, or for quizzes. For each new technique or problem covered in this book, there are at least two hands-on problems. One of these could be used in the class and the other one could be given for homework or exam. Most hands-on exercises in chapters are also immediately followed by hands-on homework exercises that a student could try for further practice, or an instructor could assign as homework or in-class practice assignment.

Strengths and Unique Features of This Book

Data science has a very visible presence these days, and it is not surprising that there are currently several available books and much material related to the field. *A Hands-On Introduction to Data Science* is different from the other books in several ways.

- It is targeted to students with very basic experience with technology. Students who fit in that category are majoring in information science, business, psychology, sociology, education, health, cognitive science, and indeed any area in which data can be applied. The study of data science should not be limited to those studying computer science or statistics. This book is intended for those audiences.
- The book starts by introducing the field of data science without any prior expectation of knowledge on the part of the reader. It then introduces the reader to some foundational ideas and techniques that are independent of technology. This does two things: (1) it provides an easier access point for a student without strong technical background; and (2) it presents material that will continue to be relevant even when tools and technologies change.
- Based on my own teaching and curriculum development experiences, I have found that most data science books on the market are divided into two categories: they are either too technical, making them suitable only for a limited audience, or they are structured to be

simply informative, making it hard for the reader to actually use and apply data science tools and techniques. *A Hands-On Introduction to Data Science* is aimed at a nice middle ground: On the one hand, it is not simply describing data science, but also teaching real hands-on tools (Python, R) and techniques (from basic regression to various forms of machine learning). On the other hand, it does not require students to have a strong technical background to be able to learn and practice data science.

- *A Hands-On Introduction to Data Science* also examines implications of the use of data in areas such as privacy, ethics, and fairness. For instance, it discusses how unbalanced data used without enough care with a machine learning technique could lead to biased (and often unfair) predictions. There is also an introduction to the newly formulated General Data Protection Regulations (GDPR) in Europe.
- The book provides many examples of real-life applications, as well as practices ranging from small to big data. For instance, Chapter 4 has an example of working with housing data where simple UNIX commands could extract valuable insights. In Chapter 5, we see how multiple linear regression can be easily implemented using Python to learn how advertising spending on various media (TV, radio) could influence sales. Chapter 6 includes an example that uses R to analyze data about wines to predict which ones are of high quality. Chapters 8–10 on machine learning have many real-life and general interest problems from different fields as the reader is introduced to various techniques. Chapter 11 has hands-on exercises for collecting and analyzing social media data from services such as Twitter and YouTube, as well as working with large datasets (Yelp data with more than a million records). Many of the examples can be worked by hand or with everyday software, without requiring specialized tools. This makes it easier for a student to grasp a concept without having to worry about programming structures. This allows the book to be used for non-majors as well as professional certificate courses.
- Each chapter has plenty of in-chapter exercises where I walk the reader through solving a data problem using a new technique, homework exercises to do more practice, and more hands-on problems (often using real-life data) at the end of the chapters. There are 37 hands-on solved exercises, 46 hands-on try-it-yourself exercises, and 55 end-of-chapter hands-on problems.
- The book is supplemented by a generous set of material for instructors. These instructor resources include curriculum suggestions (even full-length syllabuses for some courses), slides for each chapter, datasets, program scripts, answers and solutions to each exercise, as well as sample mid-term exams and final projects.

About the Author



Dr. Chirag Shah is Associate Professor at University of Washington in Seattle. Before, he was a faculty member at Rutgers University. He is a Senior Member of the Association for Computing Machinery (ACM). He received his Ph.D. in Information Science from University of North Carolina at Chapel Hill and a M.S. in Computer Science from the University of Massachusetts at Amherst.

His research interests include studies of interactive information seeking and retrieval, with applications to personalization and recommendation, as well as applying machine learning and data mining techniques to both big data and tiny data problems. He has published several books and peer-reviewed articles in the areas of information seeking and social media. He has developed Coagmento system for collaborative and social searching, IRIS (Information Retrieval and Interaction System) for investigating and implementing interactive IR activities, as well as several systems for collecting and analyzing data from social media channels, including award winning ContextMiner, InfoExtractor, TubeKit, and SOCRATES. He directs the InfoSeeking Lab, where he investigates issues related to information seeking, social media, and neural information retrieval. These research projects are supported by grants from the National Science Foundation (NSF), the National Institute of Health (NIH), the Institute of Museum and Library Services (IMLS), Amazon, Google, and Yahoo!. He also serves as a consultant to the United Nations Data Analytics on various data science projects involving social and political issues, peacekeeping, climate change, and energy. He spent his last sabbatical at Spotify as a Visiting Research Scientist and is currently consulting to Amazon on personalization and recommendation problems as an Amazon Scholar.

Dr. Shah has taught extensively to both undergraduate and graduate (masters and Ph.D.) students on topics of data science, machine learning, information retrieval (IR), human-computer interaction (HCI), and quantitative research methods. He has

also delivered special courses and tutorials at various international venues, and created massive open online courses (MOOCs) for platforms such as Coursera. He has developed several courses and curricula for data science and advised dozens of undergraduate and graduate students pursuing data science careers. This book is a result of his many years of teaching, advising, researching, and realizing the need for such a resource.

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My sweet and smart daughters – Sophie, Zoe, and Sarah – have also kept me connected to the reality while I worked on this book. They have inspired me to look beyond data and information to appreciate the human values behind them. After all, why bother doing anything in this book if it is not helping human knowledge and advancement in some way? I am constantly amazed by my kids' curiosity and sense of adventure, because those are the qualities one needs in doing any kind of science, and certainly data science. A lot of the analyses and problem solving presented in this book fall under this category, where we are not simply processing some data, but are driven by a sense of curiosity and a quest to derive new knowledge.

This book, as I have noted in the Preface, happened organically over many years through developing and teaching various data science classes. And so I need to thank all of those students who sat in my classes or joined online, went through my material, asked questions, provided feedback, and helped me learn more. With every iteration of every class I have taught in data science, things have gotten better. In essence, what you are holding in your hands is the result of the best iteration so far.

In addition to hundreds (or thousands, in the case of MOOCs) of students over the years, there are specific students and assistants I need to thank for their direct and substantial contributions to this book. My InfoSeeking Lab assistants Liz Smith and Catherine McGowan have been tremendously helpful in not only proofreading, but also helping with literature review and contributing several pieces of writings. Similarly, Dongho Choi and Soumik Mandal, two of my Ph.D. students, have contributed substantially to some of the writings and many of the examples and exercises presented in this book. If it was not for the help and dedication of these four people, this book would have been delayed by at least a year.

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