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# Preface

## Intended Audience

As the title suggests, this book is intended as an introduction to both the foundations and applications of statistics. It is an introduction in the sense that it does not assume a prior statistics course. But it is not introductory in the sense of being suitable for students who have had nothing more than the usual high school mathematics preparation. The target audience is undergraduate students at the equivalent of the junior or senior year at a college or university in the United States.

Students should have had courses in differential and integral calculus, but not much more is required in terms of mathematical background. In fact, most of my students have had at least another course or two by the time they take this course, but the only courses that they have all had is the calculus sequence. The majority of my students are not mathematics majors. I have had students from biology, chemistry, computer science, economics, engineering, and psychology, and I have tried to write a book that is interesting, understandable, and useful to students with a wide range of backgrounds and career goals.

This book is suitable for what is often a two-semester sequence in “mathematical statistics”, but it is different in some important ways from many of the books written for such a course. I was trained as a mathematician first, and the book is clearly mathematical at some points, but the emphasis is on the statistics. Mathematics and computation are brought in where they are useful tools. The result is a book that stretches my students in different directions at different times – sometimes statistically, sometimes mathematically, sometimes computationally.

## The Approach Used in This Book

Features of this book that help distinguish it from other books available for such a course include the following:

- The use of R, a free software environment for statistical computing and graphics, throughout the text.

Many books claim to integrate technology, but often technology appears to be more of an afterthought. In this book, topics are selected, ordered, and discussed in light of the current practice in statistics, where computers are an indispensable tool, not an occasional add-on.

R was chosen because it is both powerful and available. Its “market share” is increasing rapidly, so experience with R is likely to serve students well in their future careers in industry or academics. A large collection of add-on packages are available, and new statistical methods are often available in R before they are available anywhere else.

R is open source and is available at the Comprehensive R Archive Network (CRAN, <http://cran.r-project.org>) for a wide variety of computing platforms at no cost. This allows students to obtain the software for their personal computers – an essential ingredient if computation is to be used throughout the course.

The R code in this book was executed on a 2.66 GHz Intel Core 2 Duo MacBook Pro running OS X (version 10.5.8) and the current version of R (version 2.12). Results using a different computing platform or different version of R should be similar.

- An emphasis on practical statistical reasoning.

The idea of a statistical study is introduced early on using Fisher’s famous example of the lady tasting tea. Numerical and graphical summaries of data are introduced early to give students experience with R and to allow them to begin formulating statistical questions about data sets even before formal inference is available to help answer those questions.

- Probability *for* statistics.

One model for the undergraduate mathematical statistics sequence presents a semester of probability followed by a semester of statistics. In this book, I take a different approach and get to statistics early, developing the necessary probability as we go along, motivated by questions that are primarily statistical. Hypothesis testing is introduced almost immediately, and p-value computation becomes a motivation for several probability distributions. The binomial test and Fisher’s exact test are introduced formally early on, for example. Where possible, distributions are presented as statistical models first, and their properties (including the probability mass function or probability density function) derived, rather than the other way around. Joint distributions are motivated by the desire to learn about the sampling distribution of a sample mean.

Confidence intervals and inference for means based on  $t$ -distributions must wait until a bit more machinery has been developed, but my intention is that a student who only takes the first semester of a two-semester sequence will have a solid understanding of inference for one variable – either quantitative or categorical.

- The linear algebra middle road.

Linear models (regression and ANOVA) are treated using a geometric, vector-based approach. A more common approach at this level is to introduce these topics without referring to the underlying linear algebra. Such an approach avoids the problem of students with minimal background in linear algebra but leads to mysterious and unmotivated identities and notions.

Here I rely on a small amount of linear algebra that can be quickly reviewed or learned and is based on geometric intuition and motivation (see Appendix C). This works well in conjunction with R since R is in many ways vector-based and facilitates vector and matrix operations. On the other hand, I avoid using an approach that is too abstract or requires too much background for the typical student in my course.

## Brief Outline

The first four chapters of this book introduce important ideas in statistics (distributions, variability, hypothesis testing, confidence intervals) while developing a mathematical and computational toolkit. I cover this material in a one-semester course. Also, since some of my students only take the first semester, I wanted to be sure that they leave with a sense for statistical practice and have some useful statistical skills even if they do not continue. Interestingly, as a result of designing my course so that stopping halfway makes some sense, I am finding that more of my students are continuing on to the second semester. My sample size is still small, but I hope that the trend continues and would like to think it is due in part because the students are enjoying the course and can see “where it is going”.

The last three chapters deal primarily with two important methods for handling more complex statistical models: maximum likelihood and linear models (including regression, ANOVA, and an introduction to generalized linear models). This is not a comprehensive treatment of these topics, of course, but I hope it both provides flexible, usable statistical skills and prepares students for further learning.

Chi-squared tests for goodness of fit and for two-way tables using both the Pearson and likelihood ratio test statistics are covered after first generating empirical p-values based on simulations. The use of simulations here reinforces the notion of a sampling distribution and allows for a discussion about what makes a good test statistic when multiple test statistics are available. I have also included a brief introduction to Bayesian inference, some examples that use simulations to investigate robustness, a few examples of permutation tests, and a discussion of Bradley-Terry models. The latter topic is one that I cover between Selection Sunday and the beginning of the NCAA Division I Basketball Tournament each year. An application of the method to the 2009–2010 season is included.

Various R functions and methods are described as we go along, and Appendix A provides an introduction to R focusing on the way R is used in the rest of the book. I recommend working through Appendix A simultaneously with the first chapter – especially if you are unfamiliar with programming or with R.

Some of my students enter the course unfamiliar with the notation for things like sets, functions, and summation, so Appendix B contains a brief tour of the basic

mathematical results and notation that are needed. The linear algebra required for parts of Chapter 4 and again in Chapters 6 and 7 is covered in Appendix C. These can be covered as needed or used as a quick reference. Appendix D is a review of the first four chapters in outline form. It is intended to prepare students for the remainder of the book after a semester break, but it could also be used as an end of term review.

### Access to R Code and Data Sets

All of the data sets and code fragments used in this book are available for use in R on your own computer. Data sets and other utilities that are not provided by R packages in CRAN are available in the `fastR` package. This package can be obtained from CRAN, from the companion web site for this book, or from the author's web site.

Among the utility functions in `fastR` is the function `snippet()`, which provides easy access to the code fragments that appear in this book. The names of the code fragments in this book appear in boxes at the right margin where code output is displayed. Once `fastR` has been installed and loaded,

```
| snippet('snippet')
```

will both display and execute the code named “snippet”, and

```
| snippet('snippet', exec=FALSE)
```

will display but not execute the code.

`fastR` also includes a number of additional utility functions. Several of these begin with the letter `x`. Examples include `xplot`, `xhistogram`, `xpnorm`, etc. These functions add extra features to the standard functions they are based on. In most cases they are identical to their `x`-less counterparts unless new arguments are used.

### Companion Web Site

Additional material related to this book is available online at

<http://www.ams.org/bookpages/amstext-13>

Included there are

- an errata list,
- additional instructions, with links, for installing R and the R packages used in this book,
- additional examples and problems,
- additional student solutions,
- additional material – including a complete list of solutions – available only to instructors.

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Alas, despite the efforts of so many, this book is still not perfect. No books are perfect, but some books are useful. My hope is that this book is both useful and enjoyable. A list of those (I hope few) errors that have escaped detection until after the printing of this book will be maintained at

<http://www.ams.org/bookpages/amstext-13>

My thanks in advance to those who bring these to my attention.