Preface to the Third Edition

This text is intended to provide a strong theoretical background in testing hypotheses and decision theory for those who will be practicing in the real world or who will be participating in the training of real-world statisticians and biostatisticians. In previous editions of this text, my rhetoric was somewhat tentative. I was saying, in effect, "Gee guys, permutation methods provide a practical real-world alternative to asymptotic parametric approximations. Why not give them a try?" But today, the theory, the software, and the hardware have come together. Distribution-free permutation procedures are the primary method for testing hypotheses. Parametric procedures and the bootstrap are to be reserved for the few situations in which they may be applicable. Four factors have forced this change:

1. Desire by workers in applied fields to use the most powerful statistic for their applications. Such workers may not be aware of the fundamental lemma of Neyman and Pearson, but they know that the statistic they want to use—a complex score or a ratio of scores, does not have an already well-tabulated distribution.
2. Pressure from regulatory agencies for the use of methods that yield exact significance levels, not approximations.
3. A growing recognition that most real-world data are drawn from mixtures of populations.
4. A growing recognition that missing data is inevitable, balanced designs the exception.

Thus, it seems natural that the theory of testing hypothesis and the more general decision theory in which it is embedded should be introduced via the permutation tests. On the other hand, certain relatively robust parametric tests such as Student's t continue to play an essential role in statistical practice.

As the present edition is intended to replace rather than supplement existing graduate level texts on testing hypotheses and decision theory, it includes material on parametric methods as well as the permutation tests and the bootstrap. The revised and expanded text includes many more real-world illustrations from economics, geology, law, and clinical trials. Also included in this new edition are a chapter on multifactor designs expounding on the theory of synchronous permutations developed by Fortunato Pesarin and his colleagues and sections on sequential analysis and adaptive treatment allocation.

Algebra and an understanding of discrete probability will take the reader through all but the appendix, which utilizes probability measures in its proofs. A one-semester graduate course would take the student through Chapters 1–3 and any portions of Chapters 4, 5, and Appendix that seem appropriate. The second semester would take the student through Chapters 6 and 7, and whatever portions of the remaining chapters seem germane to the instructor and students' interests.

An appendix utilizing measure theory has been provided for the benefit of the reader and instructor who may wish to have a mathematically rigorous foundation for the theory of testing hypotheses for continuous as well as discrete variables. For example, Section 2 of the appendix extends the proof of the Fundamental Lemma in Chapter 3 to the continuous case.

The number of exercises has been greatly increased from previous editions. Exercises range from the concept-driven, designed to develop the student's statistical intuition in practical settings, to the highly mathematical. Instructors are free to pick and choose in accordance with the mathematical and practical sophistication of their classes and the objectives of their courses.

To ensure greater comprehension of fundamental concepts, many essential results are now presented in the form of exercises. Although the primary motivation for this change came from instructors, feedback from the autodidact has persuaded us that full understanding can only be gained from actual usage.

Hopefully, this edition reflects the lessons I've learned from a series of interactive on-line courses offered through statistics.com. Immediate feedback from my students has forced me to revise the text again and again. The late Joseph Hodges once said, "The ideal mathematics lecture would be entirely free of symbols." The current text avoids symbols to the degree I am capable of doing so, their occasional use a weakness. Asymptotic results are avoided; the emphasis in this strongly theoretical work is on the practical.

If you find portions of this text particularly easy to understand the credit goes to Cliff Lunneborg for his insightful review of the entire text, to Fortunato Pesarin for his many contributions to Chapter 9, and to Norman Marshall for his comments on Chapter 8.

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Preface to the Second Edition

In 1982, I published several issues of a *samdizat* scholarly journal called *Randomization* with the aid of an 8-bit, 1-MH personal computer with 48 K of memory (upgraded to 64 K later that year) and floppy disks that held 400 Kbytes. A decade later, working on the first edition of this text, I used a 16-bit, 33-MH computer with 1 Mb of memory and a 20-Mb hard disk. This preface to the second edition comes to you via a 32-bit, 300-MH computer with 64-Mb memory and a 4-Gb hard disk. And, yes, I paid a tenth of what I paid for my first computer.

This relationship between low-cost readily available computing power and the rising popularity of permutation tests is no coincidence. Simply put, it is faster today to compute an exact p-value than to look up an approximation in a table of the not-quite-appropriate statistic. As a result, more and more researchers are using Permutation Tests to analyze their data.

Of course, some of the increased usage has also come about through the increased availability of and improvements in off-the-shelf software, as can be seen in the revisions in this edition to Chapter 12 (Publishing Your Results) and Chapter 13 (Increasing Computation Efficiency).

These improvements helped persuade me it was the time to publish a first course in statistics based entirely on resampling methods (an idea first proposed by the late F.N. David). As a result, *Permutation Tests* has become two texts: one, *Resampling Methods*, designed as a first course, and this second edition aimed at upper division graduate students and practitioners who may already be familiar with the application of other statistical procedures. The popular question section at the end of each chapter now contains a number of thesis-level questions, which may or may not be solvable in their present form. While the wide applicability of permutation tests continues to be emphasized here, their limitations are also revealed. Examples include expanded sections on comparing variances (Chapter 3, Testing Hypotheses), testing interactions in balanced designs (Chapter 4, Experimental Design), and multiple regression (Chapter 7, Dependence).

Sections on sequential analysis (Chapter 4) and comparing spatial distributions (Chapter 8) are also new. Recent major advances in the analysis of multiple dependent tests are recorded in Chapter 5 on multivariate analysis.

My thanks to the many individuals who previewed chapters for this edition, including, in alphabetical order, Brian Cade, Mike Ernst, Barbara Heller, John Kimmel, Patrick Onghena, Fortunato Pesarin, and John Thaden.

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Preface to the First Edition

Permutation tests permit us to choose the test statistic best suited to the task at hand. This freedom of choice opens up a thousand practical applications, including many which are beyond the reach of conventional parametric statistics. Flexible, robust in the face of missing data and violations of assumptions, the permutation test is among the most powerful of statistical procedures. Through sample size reduction, permutation tests can reduce the costs of experiments and surveys.

This text on the application of permutation tests in biology, medicine, science, and engineering may be used as a step-by-step self-guiding reference manual by research workers and as an intermediate text for undergraduates and graduates in statistics and the applied sciences with a first course in statistics and probability under their belts.

Research workers in the applied sciences are advised to read through Chapters 1 and 2 once quickly before proceeding to Chapters 3 through 8, which cover the principal applications they are likely to encounter in practice.

Chapter 9 is a must for the practitioner, with advice for coping with real-life emergencies such as missing or censored data, after-the-fact covariates, and outliers.

Chapter 10 uses practical applications in archeology, biology, climatology, education, and social science to show the research worker how to develop new permutation statistics to meet the needs of specific applications. The practitioner will find Chapter 10 a source of inspiration as well as a practical guide to the development of new and novel statistics.

The expert system in Chapter 11 will guide you to the correct statistic for your application. Chapter 12, more "must" reading, provides practical advice on experimental design and shows how to document the results of permutation tests for publication.

Chapter 13 describes techniques for reducing computation time; a guide to off-the-shelf statistical software is provided in an appendix.

The sequence of recommended readings is somewhat different for the student and will depend on whether he or she is studying the permutation tests by themselves or as part of a larger course on resampling methods encompassing both the permutation test and the bootstrap resampling method.

This book can replace a senior-level text on testing hypotheses. I have also found it of value in introducing students who are primarily mathematicians to the applications which make statistics a unique mathematical science. Chapters 1, 2, and 14 provide a comprehensive introduction to the theory. Despite its placement in the latter part of the text, Chapter 14, on the theory of permutation tests, is self-standing. Chapter 3 on applications also deserves a careful reading. Here in detail are the basic testing situations and the basic tests to be applied to them. Chapters 4, 5, and 6 may be used to supplement Chapter 3, time permitting (the first part of Chapter 6 describing the Fisher exact test is a must). Rather than skipping from section to section, it might be best for the student to consider one of these latter chapters in depth—supplementing his or her study with original research articles.

My own preference is to parallel discussions of permutation methods with discussion of a second resampling method, the bootstrap. Again, Chapters 1, 2, and 3—supplemented with portions of Chapter 14—are musts. Chapter 7, on tests of dependence, is a natural sequel. Students in statistical computing also are asked to program and test at least one of the advanced algorithms in Chapter 12.

For the reader's convenience the bibliography is divided into four parts: the first consists of 34 seminal articles; the second of two dozen background articles referred to in the text that are not directly concerned with permutation methods; the third of 111 articles on increasing computational efficiency; and a fourth, principal bibliography of 574 articles and books on the theory and application of permutation techniques.

Exercises are included at the end of each chapter to enhance and reinforce your understanding. But the best exercise of all is to substitute your own data for the examples in the text.

My thanks to Symantek, TSSI, and Perceptronics without whose GrandView® outliner, Exact® equation generator, and Einstein Writer® word processor this text would not have been possible.

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