国外电子与通信教材系列

英文版

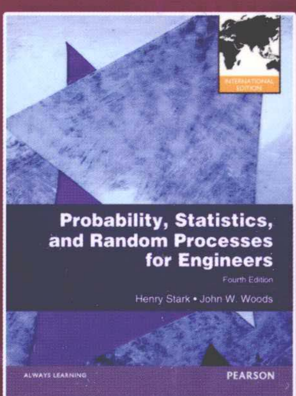
PEARSON

概率、统计与随机过程

（第四版）

Probability, Statistics, and Random Processes for Engineers

Fourth Edition



［美］ Henry Stark
John W. Woods 著

電子工業出版社
PUBLISHING HOUSE OF ELECTRONICS INDUSTRY
http://www.phei.com.cn

国外电子与通信教材系列

概率、统计与随机过程

（第四版）（英文版）

Probability, Statistics, and Random Processes for Engineers

Fourth Edition

［美］ Henry Stark
John W. Woods 著

電子工業出版社
Publishing House of Electronics Industry
北京 · BEIJING

内容简介

本书从工程应用的角度，全面阐述概率、统计与随机过程的基本理论及其应用。全书共11章（其中第10章和第11章为网上资源），首先简单介绍概率论，然后各章分别讨论随机变量、随机变量的函数、均值与矩、随机矢量、统计（包括参数估计和假设检验）、随机序列、随机过程基础知识和深入探讨，最后讨论了统计信号处理中的相关应用。书中给出了大量电子和信息系统相关实例，每章给出了丰富的习题。

本书适合作为电子信息类专业本科生和研究生的“随机信号分析”或“随机过程及其应用”课程的双语教学教材，也可供从事相关技术领域研究的科技人员参考。

版权贸易合同登记号 图字：01-2012-5644

图书在版编目（CIP）数据

概率、统计与随机过程：第4版 = Probability, Statistics, and Random Processes for Engineers：英文 /（美）斯塔克（Stark, H.），（美）伍兹（Woods, J. W.）著. —北京：电子工业出版社，2012.8
国外电子与通信教材系列
ISBN 978-7-121-17668-5

Ⅰ. ①概… Ⅱ. ①斯… ②伍… Ⅲ. ①概率论－高等学校－教材－英文 ②数理统计－高等学校－教材－英文 ③随机过程－高等学校－教材－英文 Ⅳ. ① O21

中国版本图书馆CIP数据核字（2012）第161886号

策划编辑：马 岚
责任编辑：马 岚
印 刷：北京京师印务有限公司
装 订：
出版发行：电子工业出版社
北京市海淀区万寿路173信箱 邮编：100036
开 本：787 × 980 1/16 印张：44 字数：1281千字
印 次：2012年8月第1次印刷
定 价：89.00元

凡所购买电子工业出版社的图书有缺损问题，请向购买书店调换；若书店售缺，请与本社发行部联系。联系及邮购电话：（010）88254888。
质量投诉请发邮件至zlts@phei.com.cn，盗版侵权举报请发邮件至dbqq@phei.com.cn。
服务热线：（010）88258888。

Contents

登录华信教育资源网（http://www.hxedu.com.cn）可下载第 10 章和第 11 章。
采用本书作为教材的教师可获得本书配套教辅，请联系 010–88254555 或发邮件至 te_services@phei.com.cn

Preface

While significant changes have been made in the current edition from its predecessor, the authors have tried to keep the discussion at the same level of accessibly, that is, less mathematical than the measure theory approach but more rigorous than formula and recipe manuals.

It has been said that *probability* is hard to understand, not so much because of its mathematical underpinnings but because it produces many results that are counter intuitive. Among practically oriented students, *Probability* has many critics. Foremost among these are the ones who ask, "What do we need it for?" This criticism is easy to answer because future engineers and scientists will come to realize that almost every human endeavor involves making decisions in an uncertain or probabilistic environment. This is true for entire fields such as insurance, meteorology, urban planning, pharmaceuticals, and many more. Another, possibly more potent, criticism is, "What good is probability if the answers it furnishes are not certainties but just inferences and likelihoods?" The answer here is that an immense amount of good planning and accurate predictions can be done even in the realm of uncertainty. Moreover, applied probability—often called *statistics*—does provide near certainties: witness the enormous success of political polling and prediction.

In previous editions, we have treaded lightly in the area of statistics and more heavily in the area of random processes and signal processing. In the electronic version of this book, graduate-level signal processing and advanced discussions of random processes are retained, along with new material on statistics. In the hard copy version of the book, we have dropped the chapters on applications to statistical signal processing and advanced topics in random processes, as well as some introductory material on pattern recognition.

The present edition makes a greater effort to reach students with more expository examples and more detailed discussion. We have minimized the use of phrases such as, "it is easy to show...", "it can be shown...", "it is easy to see...," and the like. Also, we have tried to furnish examples from real-world issues such as the efficacy of drugs, the likelihood of contagion, and the odds of winning at gambling, as well as from digital communications, networks, and signals.

The other major change is the addition of two chapters on elementary statistics and its applications to real-world problems. The first of these deals with parameter estimation and the second with hypothesis testing. Many activities in engineering involve estimating parameters, for example, from estimating the strength of a new concrete formula to estimating the amount of signal traffic between computers. Likewise many engineering activities involve making decisions in random environments, from deciding whether new drugs are effective to deciding the effectiveness of new teaching methods. The origin and applications of standard statistical tools such as the t-test, the Chi-square test, and the F-test are presented and discussed with detailed examples and end-of-chapter problems.

Finally, many self-test multiple-choice exams are now available for students at the book Web site. These exams were administered to senior undergraduate and graduate students at the Illinois Institute of Technology during the tenure of one of the authors who taught there from 1988 to 2006. The Web site also includes an extensive set of small MATLAB programs that illustrate the concepts of probability.

In summary then, readers familiar with the 3rd edition will see the following significant changes:

- A new chapter on a branch of statistics called *parameter estimation* with many illustrative examples;
- A new chapter on a branch of statistics called *hypothesis testing* with many illustrative examples;
- A large number of new homework problems of varying degrees of difficulty to test the student's mastery of the principles of statistics;
- A large number of self-test, multiple-choice, exam questions calibrated to the material in various chapters available on the Companion Web site.
- Many additional illustrative examples drawn from real-world situations where the principles of probability and statistics have useful applications;
- A greater involvement of computers as teaching/learning aids such as (i) graphical displays of probabilistic phenomena; (ii) MATLAB programs to illustrate probabilistic concepts; (iii) homework problems requiring the use of MATLAB/ Excel to realize probability and statistical theory;
- Numerous revised discussions—based on student feedback—meant to facilitate the understanding of difficult concepts.

Henry Stark, IIT
Professor Emeritus

John W. Woods, Rensselaer
Professor

The publishers would like to thank Dr Murari Mitra and Dr Tamaghna Acharya of Bengal Engineering and Science University for reviewing content for the International Edition.

1 Introduction to Probability

1.1 INTRODUCTION: WHY STUDY PROBABILITY?

One of the most frequent questions posed by beginning students of probability is, "Is anything truly random and if so how does one differentiate between the truly random and that which, because of a lack of information, is treated as random but really isn't?" First, regarding the question of truly random phenomena, "Do such things exist?" As we look with telescopes out into the universe, we see vast arrays of galaxies, stars, and planets in apparently random order and position.

At the other extreme from the cosmic scale is what happens at the atomic level. Our friends the physicists speak of such things as the *probability* of an atomic system being in a certain state. The uncertainty principle says that, try as we might, there is a limit to the accuracy with which the position and momentum can be simultaneously ascribed to a particle. Both quantities are fuzzy and indeterminate.

Many, including some of our most famous physicists, believe in an essential randomness of nature. Eugen Merzbacher in his well-known textbook on quantum mechanics [1-1] writes,

> The probability doctrine of quantum mechanics asserts that the indetermination, of which we have just given an example, is a property inherent in nature and not merely a profession of our temporary ignorance from which we expect to be relieved by a future better and more complete theory. The conventional interpretation thus denies the possibility of an ideal theory which would encompass the present quantum mechanics

but would be free of its supposed defects, the most notorious "imperfection" of quantum mechanics being the abandonment of strict classical determinism.

But the issue of determinism versus inherent indeterminism need never even be considered when discussing the validity of the probabilistic approach. The fact remains that there is, quite literally, a nearly uncountable number of situations where we cannot make any categorical deterministic assertion regarding a phenomenon because we cannot measure all the contributing elements. Take, for example, predicting the value of the noise current $i(t)$ produced by a thermally excited resistor R. Conceivably, we might accurately predict $i(t)$ at some instant t in the future if we could keep track, say, of the 10^{23} or so excited electrons moving in each other's magnetic fields and setting up local field pulses that eventually all contribute to producing $i(t)$. Such a calculation is quite inconceivable, however, and therefore we use a probabilistic model rather than Maxwell's equations to deal with resistor noise. Similar arguments can be made for predicting the weather, the outcome of tossing a real physical coin, the time to failure of a computer, dark current in a CMOS imager, and many other situations. Thus, we conclude: Regardless of which position one takes, that is, determinism versus indeterminism, we are forced to use probabilistic models in the real world because we do not know, cannot calculate, or cannot measure all the forces contributing to an effect. The forces may be too complicated, too numerous, or too faint.

Probability is a mathematical model to help us study physical systems in an *average sense*. We have to be able to repeat the experiment many times under the same conditions. Probability then tells us how often to expect the various outcomes. Thus, we cannot use probability in any meaningful sense to answer questions such as "What is the probability that a comet will strike the earth tomorrow?" or "What is the probability that there is life on other planets?" The problem here is that we have no data from similar "experiments" in the past.

R. A. Fisher and R. Von Mises, in the first third of the twentieth century, were largely responsible for developing the groundwork of modern probability theory. The modern axiomatic treatment upon which this book is based is largely the result of the work by Andrei N. Kolmogorov [1-2].

1.2 THE DIFFERENT KINDS OF PROBABILITY

There are essentially four kinds of probability. We briefly discuss them here.

Probability as Intuition

This kind of probability deals with judgments based on intuition. Thus, "She will probably marry him" and "He probably drove too fast" are in this category. Intuitive probability can lead to contradictory behavior. Joe is still likely to buy an imported Itsibitsi, world famous for its reliability, even though his neighbor Frank has a 19-year-old Buick that has never broken down and Joe's other neighbor, Bill, has his Itsibitsi in the repair shop. Here Joe may be behaving "rationally," going by the statistics and ignoring, so-to-speak, his personal observation. On the other hand, Joe will be wary about letting his nine-year-old daughter Jane swim in the local pond, if Frank reports that Bill thought that he might have seen an alligator in it. This despite the fact that no one has ever reported seeing an alligator in this pond, and countless people have enjoyed swimming in it without ever having been bitten by an alligator. To give this example some credibility, assume that the pond is in Florida. Here Joe is ignoring the statistics and reacting to, what is essentially, a rumor. Why? Possibly because the *cost* to Joe "just-in-case" there is an alligator in the pond would be too high [1-3].

People buying lottery tickets intuitively believe that certain number combinations like month/day/year of their grandson's birthday are more likely to win than say, 06–06–06. How many people will bet even odds that a coin that, heretofore has behaved "fairly," that is, in an unbiased fashion, will come up heads on the next toss, *if in the last seven tosses it has come up heads?* Many of us share the belief that the coin has some sort of memory and that, after seven heads, that coin must "make things right" by coming up with more tails.

A mathematical theory dealing with intuitive probability was developed by B. O. Koopman [1-4]. However, we shall not discuss this subject in this book.

Probability as the Ratio of Favorable to Total Outcomes (Classical Theory)

In this approach, which is not experimental, the probability of an event is computed *a priori*[†] by counting the number of ways n_E that E can occur and forming the ratio n_E/n, where n is the number of all possible outcomes, that is, the number of all alternatives to E plus n_E. An important notion here is that all outcomes are equally likely. Since equally likely is really a way of saying equally probable, the reasoning is somewhat circular. Suppose we throw a pair of unbiased six-sided dice[‡] and ask what is the probability of getting a 7. We partition the outcome space into 36 equally likely outcomes as shown in Table 1.2-1, where each entry is the sum of the numbers on the two dice.

Table 1.2-1 Outcomes of Throwing Two Dice

	1st die					
2nd die	1	2	3	4	5	6
1	2	3	4	5	6	7
2	3	4	5	6	7	8
3	4	5	6	7	8	9
4	5	6	7	8	9	10
5	6	7	8	9	10	11
6	7	8	9	10	11	12

[†] *A priori* means relating to reasoning from self-evident propositions or prior experience. The related phrase, *a posteriori* means relating to reasoning from observed facts.

[‡] We will always assume that our dice have six sides.

The total number of outcomes is 36 if we keep the dice distinct. The number of ways of getting a 7 is $n_7 = 6$. Hence

$$P[\text{getting a 7}] = \frac{6}{36} = \frac{1}{6}.$$

Example 1.2-1

(*toss a fair coin twice*) The possible outcomes are HH, HT, TH, and TT. The probability of getting at least one tail T is computed as follows: With E denoting the event of getting at least one tail, the event E is the set of outcomes

$$E = \{\text{HT}, \text{TH}, \text{TT}\}.$$

Thus, event E occurs whenever the outcome is HT or TH or TT. The number of elements in E is $n_E = 3$; the number of all outcomes N, is four. Hence

$$P[\text{at least one T}] = \frac{n_E}{n} = \frac{3}{4}.$$

Note that since no physical experimentation is involved, there is no problem in postulating an ideal "fair coin." Effectively, in classical probability every experiment is considered "fair."

The classical theory suffers from at least two significant problems: (1) It cannot deal with outcomes that are not equally likely; and (2) it cannot handle an infinite number of outcomes, that is when $n = \infty$. Nevertheless, in those problems where it is impractical to actually determine the outcome probabilities by experimentation and where, because of symmetry considerations, one can indeed argue equally likely outcomes, the classical theory is useful.

Historically, the classical approach was the predecessor of Richard Von Mises' [1-6] relative frequency approach developed in the 1930s, which we consider next.

Probability as a Measure of Frequency of Occurrence

The relative frequency approach to defining the probability of an event E is to perform an experiment n times. The number of times that E appears is denoted by n_E. Then it is tempting to define the probability of E occurring by

$$P[E] = \lim_{n\to\infty} \frac{n_E}{n}. \tag{1.2-1}$$

Quite clearly since $n_E \leq n$ we must have $0 \leq P[E] \leq 1$. One difficulty with this approach is that we can never perform the experiment an infinite number of times, so we can only estimate $P[E]$ from a finite number of trials. Secondly, we *postulate* that n_E/n approaches a limit as n goes to infinity. But consider flipping a fair coin 1000 times. The likelihood of getting exactly 500 heads is very small; in fact, if we flipped the coin 10,000 times, the likelihood of getting exactly 5000 heads is even smaller. As $n \to \infty$, the event of observing