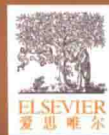


TURING

图灵原版数学·统计学系列



北美精算师考试指定参考书

Introduction to Probability Models
11th Edition

应用 随机过程 概率模型导论

[美] Sheldon M. Ross © 著

(英文版·第11版)

应用随机过程经典教材，
学习**精算学**、**人工智能**、**机器学习**的必备参考书！



中国工信出版集团



人民邮电出版社
POSTS & TELECOM PRESS

“本书的一大特色是实例丰富，内容涉及多个学科，尤其是精算学……相信任何有上进心的读者都会对此爱不释手。”

——Jean LeMaire, 宾夕法尼亚大学沃顿商学院

“书中的例子和习题非常出色，作者不仅提供了非常基本的例子，以阐述基础概念和公式，还从尽可能多的学科中提炼出许多较高级的实例，极具参考价值。”

——Matt Carlton, 加州州立理工大学 (Cal Poly)

本书是国际知名统计学家Sheldon M. Ross所著的关于基础概率理论和随机过程的经典教材，被加州大学伯克利分校、哥伦比亚大学、普度大学、密歇根大学、俄勒冈州立大学、华盛顿大学等众多国外知名大学所采用。

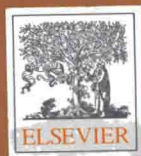
与其他随机过程教材相比，本书非常强调实践性，内含极其丰富的例子和习题，涵盖了众多学科的各种应用。作者富于启发而又不失严密性的叙述方式，有助于使读者建立概率思维方式，培养对概率理论、随机过程的直观感觉。对那些需要将概率理论应用于精算学、计算机科学、管理学和社会科学的读者而言，本书是一本极好的教材或参考书。

第11版新增大量例子和习题，还对连续时间的马尔可夫链、漂移布朗运动等内容做了修订，更加注重强化读者的概率直观。

本书译自原版 *Introduction to Probability Models, 11th Edition*,
并由Elsevier授权出版。



图灵社区: iTuring.cn
热线: (010) 51095186 转 600



ISBN 978-7-115-38474-4



ISBN 978-7-115-38474-4

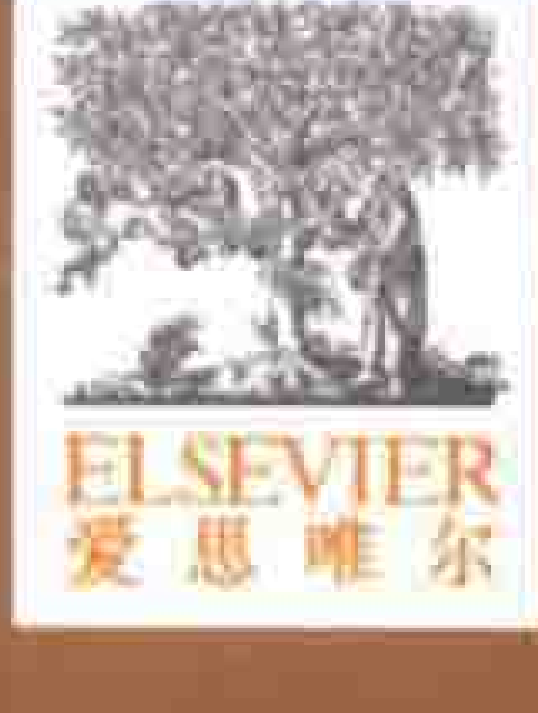
定价: 99.00元

分类建议 数学 / 概率

人民邮电出版社网址: www.ptpress.com.cn



图灵教育



应用随机过程 概率模型导论

(英文版·第11版)

[美] Sheldon M. Ross © 著

人民邮电出版社



RING

图灵原版数学·统计学系列

Introduction to Probability Models, 11th Edition

应用随机过程 概率模型导论

(英文版·第11版)

[美] Sheldon M. Ross © 著

人民邮电出版社

北京

图书在版编目 (C I P) 数据

应用随机过程：概率模型导论：第11版：英文 /
(美) 罗斯 (Ross, S. M.) 著. — 北京：人民邮电出版社，
2015. 3

(图灵原版数学·统计学系列)
ISBN 978-7-115-38474-4

I. ①应… II. ①罗… III. ①随机过程—英文 IV.
①0211. 6

中国版本图书馆CIP数据核字(2015)第018575号

内 容 提 要

本书是一部经典的随机过程著作，叙述深入浅出、涉及面广。主要内容有随机变量、条件期望、马尔可夫链、指数分布、泊松过程、平稳过程、更新理论及排队论等，也包括了随机过程在物理、生物、运筹、网络、遗传、经济、保险、金融及可靠性中的应用。特别是有关随机模拟的内容，给随机系统运行的模拟计算提供了有力的工具。最新版还增加了不带左跳的随机徘徊和生灭排队模型等内容。本书约有700道习题，其中带星号的习题还提供了解答。

本书可作为计算机科学、保险学、社会科学、生命科学、管理科学与工程等专业随机过程基础课教材。

-
- ◆ 著 [美] Sheldon M. Ross
责任编辑 朱 巍
责任印制 杨林杰
 - ◆ 人民邮电出版社出版发行 北京市丰台区成寿寺路11号
邮编 100164 电子邮件 315@ptpress.com.cn
网址 <http://www.ptpress.com.cn>
北京隆昌伟业印刷有限公司印刷
 - ◆ 开本：700×1000 1/16
印张：49
字数：782千字 2015年3月第1版
印数：1-3 000册 2015年3月北京第1次印刷
- 著作权合同登记号 图字：01-2014-5095号

定价：99.00元

读者服务热线：(010)51095186转600 印装质量热线：(010)81055316

反盗版热线：(010)81055315

广告经营许可证：京崇工商广字第 0021 号

Preface

This text is intended as an introduction to elementary probability theory and stochastic processes. It is particularly well suited for those wanting to see how probability theory can be applied to the study of phenomena in fields such as engineering, computer science, management science, the physical and social sciences, and operations research.

It is generally felt that there are two approaches to the study of probability theory. One approach is heuristic and nonrigorous and attempts to develop in the student an intuitive feel for the subject that enables him or her to “think probabilistically.” The other approach attempts a rigorous development of probability by using the tools of measure theory. It is the first approach that is employed in this text. However, because it is extremely important in both understanding and applying probability theory to be able to “think probabilistically,” this text should also be useful to students interested primarily in the second approach.

New to This Edition

The eleventh edition includes new text material, examples, and exercises. Some of the key new examples are the following.

- Example 3.6, which derives the density function of the t-random variable.
- Example 3.32, which analyzes a serve and rally competition where the winner of a rally is the server for the next point.
- Example 5.19, which considers a one lane road with no overtaking.
- Example 6.22, which uses the reverse chain to analyze a sequential queuing system.
- Example 7.20, which analyzes a system where both people and buses randomly arrive at a bus stop.

New sections include

- Section 4.4, on the long-run proportions and limiting probabilities of a Markov chain.
- Section 5.5, on random intensity functions and Hawkes processes.
- Section 6.7, on the reverse chain of continuous-time Markov chains
- Section 10.5, which analyzes the maximum variable of a Brownian motion with drift process.

We have also tried to simplify and clarify existing material wherever possible. Examples include a new proof of the result that the number of events of a non-homogeneous Poisson process that occur in an interval is Poisson distributed, as

well as the introduction of Wald's Equation (Theorem 7.2) and its subsequent use in proving the elementary renewal theorem.

Course

Ideally, this text would be used in a one-year course in probability models. Other possible courses would be a one-semester course in introductory probability theory (involving Chapters 1–3 and parts of others) or a course in elementary stochastic processes. The textbook is designed to be flexible enough to be used in a variety of possible courses. For example, I have used Chapters 5 and 8, with smatterings from Chapters 4 and 6, as the basis of an introductory course in queueing theory.

Examples and Exercises

Many examples are worked out throughout the text, and there are also a large number of exercises to be solved by students. More than 100 of these exercises have been starred and their solutions provided at the end of the text. These starred problems can be used for independent study and test preparation. An Instructor's Manual, containing solutions to all exercises, is available free to instructors who adopt the book for class.

Organization

Chapters 1 and 2 deal with basic ideas of probability theory. In Chapter 1 an axiomatic framework is presented, while in Chapter 2 the important concept of a random variable is introduced. Section 2.6.1 gives a simple derivation of the joint distribution of the sample mean and sample variance of a normal data sample.

Chapter 3 is concerned with the subject matter of conditional probability and conditional expectation. "Conditioning" is one of the key tools of probability theory, and it is stressed throughout the book. When properly used, conditioning often enables us to easily solve problems that at first glance seem quite difficult. The final section of this chapter presents applications to (1) a computer list problem, (2) a random graph, and (3) the Polya urn model and its relation to the Bose-Einstein distribution. Section 3.6.5 presents k -record values and the surprising Ignatov's theorem.

In Chapter 4 we come into contact with our first random, or stochastic, process, known as a Markov chain, which is widely applicable to the study of many real-world phenomena. Applications to genetics and production processes are presented. The concept of time reversibility is introduced and its usefulness illustrated. Section 4.5.3 presents an analysis, based on random walk theory, of a probabilistic algorithm for the satisfiability problem. Section 4.6 deals with the mean times spent in transient states by a Markov chain. Section 4.9 introduces Markov chain Monte Carlo methods. In the final section we consider a model for optimally making decisions known as a Markovian decision process.

In Chapter 5 we are concerned with a type of stochastic process known as a counting process. In particular, we study a kind of counting process known as a Poisson process. The intimate relationship between this process and the exponential

distribution is discussed. New derivations for the Poisson and nonhomogeneous Poisson processes are discussed. Examples relating to analyzing greedy algorithms, minimizing highway encounters, collecting coupons, and tracking the AIDS virus, as well as material on compound Poisson processes, are included in this chapter. Section 5.2.4 gives a simple derivation of the convolution of exponential random variables.

Chapter 6 considers Markov chains in continuous time with an emphasis on birth and death models. Time reversibility is shown to be a useful concept, as it is in the study of discrete-time Markov chains. Section 6.7 presents the computationally important technique of uniformization.

Chapter 7, the renewal theory chapter, is concerned with a type of counting process more general than the Poisson. By making use of renewal reward processes, limiting results are obtained and applied to various fields. Section 7.9 presents new results concerning the distribution of time until a certain pattern occurs when a sequence of independent and identically distributed random variables is observed. In Section 7.9.1, we show how renewal theory can be used to derive both the mean and the variance of the length of time until a specified pattern appears, as well as the mean time until one of a finite number of specified patterns appears. In Section 7.9.2, we suppose that the random variables are equally likely to take on any of m possible values, and compute an expression for the mean time until a run of m distinct values occurs. In Section 7.9.3, we suppose the random variables are continuous and derive an expression for the mean time until a run of m consecutive increasing values occurs.

Chapter 8 deals with queueing, or waiting line, theory. After some preliminaries dealing with basic cost identities and types of limiting probabilities, we consider exponential queueing models and show how such models can be analyzed. Included in the models we study is the important class known as a network of queues. We then study models in which some of the distributions are allowed to be arbitrary. Included are Section 8.6.3 dealing with an optimization problem concerning a single server, general service time queue, and Section 8.8, concerned with a single server, general service time queue in which the arrival source is a finite number of potential users.

Chapter 9 is concerned with reliability theory. This chapter will probably be of greatest interest to the engineer and operations researcher. Section 9.6.1 illustrates a method for determining an upper bound for the expected life of a parallel system of not necessarily independent components and Section 9.7.1 analyzes a series structure reliability model in which components enter a state of suspended animation when one of their cohorts fails.

Chapter 10 is concerned with Brownian motion and its applications. The theory of options pricing is discussed. Also, the arbitrage theorem is presented and its relationship to the duality theorem of linear programming is indicated. We show how the arbitrage theorem leads to the Black–Scholes option pricing formula.

Chapter 11 deals with simulation, a powerful tool for analyzing stochastic models that are analytically intractable. Methods for generating the values of arbitrarily distributed random variables are discussed, as are variance reduction methods for

increasing the efficiency of the simulation. Section 11.6.4 introduces the valuable simulation technique of importance sampling, and indicates the usefulness of tilted distributions when applying this method.

Acknowledgments

We would like to acknowledge with thanks the helpful suggestions made by the many reviewers of the text. These comments have been essential in our attempt to continue to improve the book and we owe these reviewers, and others who wish to remain anonymous, many thanks:

Mark Brown, City University of New York
Zhiqin Ginny Chen, University of Southern California
Tapas Das, University of South Florida
Israel David, Ben-Gurion University
Jay Devore, California Polytechnic Institute
Eugene Feinberg, State University of New York, Stony Brook
Ramesh Gupta, University of Maine
Marianne Huebner, Michigan State University
Garth Isaak, Lehigh University
Jonathan Kane, University of Wisconsin Whitewater
Amarjot Kaur, Pennsylvania State University
Zohel Khalil, Concordia University
Eric Kolaczyk, Boston University
Melvin Lax, California State University, Long Beach
Jean Lemaire, University of Pennsylvania
Andrew Lim, University of California, Berkeley
George Michailidis, University of Michigan
Donald Minassian, Butler University
Joseph Mitchell, State University of New York, Stony Brook
Krzysztof Osfaszewski, University of Illinois
Erol Pekoz, Boston University
Evgeny Poletsky, Syracuse University

James Propp, University of Massachusetts, Lowell

Anthony Quas, University of Victoria

Charles H. Rourke, Proofreader

David Scollnik, University of Calgary

Mary Shepherd, Northwest Missouri State University

Galen Shorack, University of Washington, Seattle

Marcus Sommereder, Vienna University of Technology

Osnat Stramer, University of Iowa

Gabor Szekeley, Bowling Green State University

Marlin Thomas, Purdue University

Henk Tijms, Vrije University

Zhenyuan Wang, University of Binghamton

Ward Whitt, Columbia University

Bo Xiang, Georgia University of Technology

Julie Zhou, University of Victoria

Contents

1	Introduction to Probability Theory	1
1.1	Introduction	1
1.2	Sample Space and Events	1
1.3	Probabilities Defined on Events	4
1.4	Conditional Probabilities	6
1.5	Independent Events	9
1.6	Bayes' Formula	11
	Exercises	14
	References	19
2	Random Variables	21
2.1	Random Variables	21
2.2	Discrete Random Variables	25
2.2.1	The Bernoulli Random Variable	26
2.2.2	The Binomial Random Variable	26
2.2.3	The Geometric Random Variable	28
2.2.4	The Poisson Random Variable	29
2.3	Continuous Random Variables	30
2.3.1	The Uniform Random Variable	31
2.3.2	Exponential Random Variables	32
2.3.3	Gamma Random Variables	33
2.3.4	Normal Random Variables	33
2.4	Expectation of a Random Variable	34
2.4.1	The Discrete Case	34
2.4.2	The Continuous Case	37
2.4.3	Expectation of a Function of a Random Variable	38
2.5	Jointly Distributed Random Variables	42
2.5.1	Joint Distribution Functions	42
2.5.2	Independent Random Variables	45
2.5.3	Covariance and Variance of Sums of Random Variables	46
2.5.4	Joint Probability Distribution of Functions of Random Variables	55
2.6	Moment Generating Functions	58

2.6.1	The Joint Distribution of the Sample Mean and Sample Variance from a Normal Population	66
2.7	The Distribution of the Number of Events that Occur	69
2.8	Limit Theorems	71
2.9	Stochastic Processes	77
	Exercises	79
	References	91
3	Conditional Probability and Conditional Expectation	93
3.1	Introduction	93
3.2	The Discrete Case	93
3.3	The Continuous Case	97
3.4	Computing Expectations by Conditioning	100
3.4.1	Computing Variances by Conditioning	111
3.5	Computing Probabilities by Conditioning	115
3.6	Some Applications	133
3.6.1	A List Model	133
3.6.2	A Random Graph	135
3.6.3	Uniform Priors, Polya's Urn Model, and Bose—Einstein Statistics	141
3.6.4	Mean Time for Patterns	146
3.6.5	The k -Record Values of Discrete Random Variables	149
3.6.6	Left Skip Free Random Walks	152
3.7	An Identity for Compound Random Variables	157
3.7.1	Poisson Compounding Distribution	160
3.7.2	Binomial Compounding Distribution	161
3.7.3	A Compounding Distribution Related to the Negative Binomial	162
	Exercises	163
4	Markov Chains	183
4.1	Introduction	183
4.2	Chapman–Kolmogorov Equations	187
4.3	Classification of States	194
4.4	Long-Run Proportions and Limiting Probabilities	204
4.4.1	Limiting Probabilities	219
4.5	Some Applications	220
4.5.1	The Gambler's Ruin Problem	220
4.5.2	A Model for Algorithmic Efficiency	223
4.5.3	Using a Random Walk to Analyze a Probabilistic Algorithm for the Satisfiability Problem	226
4.6	Mean Time Spent in Transient States	231
4.7	Branching Processes	234

4.8	Time Reversible Markov Chains	237
4.9	Markov Chain Monte Carlo Methods	247
4.10	Markov Decision Processes	251
4.11	Hidden Markov Chains	254
4.11.1	Predicting the States	259
	Exercises	261
	References	275
5	The Exponential Distribution and the Poisson Process	277
5.1	Introduction	277
5.2	The Exponential Distribution	278
5.2.1	Definition	278
5.2.2	Properties of the Exponential Distribution	280
5.2.3	Further Properties of the Exponential Distribution	287
5.2.4	Convolutions of Exponential Random Variables	293
5.3	The Poisson Process	297
5.3.1	Counting Processes	297
5.3.2	Definition of the Poisson Process	298
5.3.3	Interarrival and Waiting Time Distributions	301
5.3.4	Further Properties of Poisson Processes	303
5.3.5	Conditional Distribution of the Arrival Times	309
5.3.6	Estimating Software Reliability	320
5.4	Generalizations of the Poisson Process	322
5.4.1	Nonhomogeneous Poisson Process	322
5.4.2	Compound Poisson Process	327
5.4.3	Conditional or Mixed Poisson Processes	332
5.5	Random Intensity Functions and Hawkes Processes	334
	Exercises	338
	References	356
6	Continuous-Time Markov Chains	357
6.1	Introduction	357
6.2	Continuous-Time Markov Chains	358
6.3	Birth and Death Processes	359
6.4	The Transition Probability Function $P_{ij}(t)$	366
6.5	Limiting Probabilities	374
6.6	Time Reversibility	380
6.7	The Reversed Chain	387
6.8	Uniformization	393
6.9	Computing the Transition Probabilities	396
	Exercises	398
	References	407

7	Renewal Theory and Its Applications	409
7.1	Introduction	409
7.2	Distribution of $N(t)$	411
7.3	Limit Theorems and Their Applications	415
7.4	Renewal Reward Processes	427
7.5	Regenerative Processes	436
7.5.1	Alternating Renewal Processes	439
7.6	Semi-Markov Processes	444
7.7	The Inspection Paradox	447
7.8	Computing the Renewal Function	449
7.9	Applications to Patterns	452
7.9.1	Patterns of Discrete Random Variables	453
7.9.2	The Expected Time to a Maximal Run of Distinct Values	459
7.9.3	Increasing Runs of Continuous Random Variables	461
7.10	The Insurance Ruin Problem	462
	Exercises	468
	References	479
8	Queueing Theory	481
8.1	Introduction	481
8.2	Preliminaries	482
8.2.1	Cost Equations	482
8.2.2	Steady-State Probabilities	484
8.3	Exponential Models	486
8.3.1	A Single-Server Exponential Queueing System	486
8.3.2	A Single-Server Exponential Queueing System Having Finite Capacity	495
8.3.3	Birth and Death Queueing Models	499
8.3.4	A Shoe Shine Shop	505
8.3.5	A Queueing System with Bulk Service	507
8.4	Network of Queues	510
8.4.1	Open Systems	510
8.4.2	Closed Systems	514
8.5	The System $M/G/1$	520
8.5.1	Preliminaries: Work and Another Cost Identity	520
8.5.2	Application of Work to $M/G/1$	520
8.5.3	Busy Periods	522
8.6	Variations on the $M/G/1$	523
8.6.1	The $M/G/1$ with Random-Sized Batch Arrivals	523
8.6.2	Priority Queues	524
8.6.3	An $M/G/1$ Optimization Example	527
8.6.4	The $M/G/1$ Queue with Server Breakdown	531

8.7	The Model $G/M/1$	534
8.7.1	The $G/M/1$ Busy and Idle Periods	538
8.8	A Finite Source Model	538
8.9	Multiserver Queues	542
8.9.1	Erlang's Loss System	542
8.9.2	The $M/M/k$ Queue	544
8.9.3	The $G/M/k$ Queue	544
8.9.4	The $M/G/k$ Queue	546
	Exercises	547
	References	558
9	Reliability Theory	559
9.1	Introduction	559
9.2	Structure Functions	560
9.2.1	Minimal Path and Minimal Cut Sets	562
9.3	Reliability of Systems of Independent Components	565
9.4	Bounds on the Reliability Function	570
9.4.1	Method of Inclusion and Exclusion	570
9.4.2	Second Method for Obtaining Bounds on $r(p)$	578
9.5	System Life as a Function of Component Lives	580
9.6	Expected System Lifetime	587
9.6.1	An Upper Bound on the Expected Life of a Parallel System	591
9.7	Systems with Repair	593
9.7.1	A Series Model with Suspended Animation	597
	Exercises	599
	References	606
10	Brownian Motion and Stationary Processes	607
10.1	Brownian Motion	607
10.2	Hitting Times, Maximum Variable, and the Gambler's Ruin Problem	611
10.3	Variations on Brownian Motion	612
10.3.1	Brownian Motion with Drift	612
10.3.2	Geometric Brownian Motion	612
10.4	Pricing Stock Options	614
10.4.1	An Example in Options Pricing	614
10.4.2	The Arbitrage Theorem	616
10.4.3	The Black-Scholes Option Pricing Formula	619
10.5	The Maximum of Brownian Motion with Drift	624
10.6	White Noise	628
10.7	Gaussian Processes	630
10.8	Stationary and Weakly Stationary Processes	633

10.9 Harmonic Analysis of Weakly Stationary Processes	637
Exercises	639
References	644
11 Simulation	645
11.1 Introduction	645
11.2 General Techniques for Simulating Continuous Random Variables	649
11.2.1 The Inverse Transformation Method	649
11.2.2 The Rejection Method	650
11.2.3 The Hazard Rate Method	654
11.3 Special Techniques for Simulating Continuous Random Variables	657
11.3.1 The Normal Distribution	657
11.3.2 The Gamma Distribution	660
11.3.3 The Chi-Squared Distribution	660
11.3.4 The Beta (n, m) Distribution	661
11.3.5 The Exponential Distribution—The Von Neumann Algorithm	662
11.4 Simulating from Discrete Distributions	664
11.4.1 The Alias Method	667
11.5 Stochastic Processes	671
11.5.1 Simulating a Nonhomogeneous Poisson Process	672
11.5.2 Simulating a Two-Dimensional Poisson Process	677
11.6 Variance Reduction Techniques	680
11.6.1 Use of Antithetic Variables	681
11.6.2 Variance Reduction by Conditioning	684
11.6.3 Control Variates	688
11.6.4 Importance Sampling	690
11.7 Determining the Number of Runs	694
11.8 Generating from the Stationary Distribution of a Markov Chain	695
11.8.1 Coupling from the Past	695
11.8.2 Another Approach	697
Exercises	698
References	705
Appendix: Solutions to Starred Exercises	707
Index	759