On distribution of runs and patterns in four state trials

Jungtaek Oh*

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Abstract

From a mathematical and statistical point of view, a segment of a DNA strand can be viewed as a sequence of four-state (A, C, G, T) trials. We consider distributions of runs and patterns related to run lengths of multi-state sequences, especially for four states (A, B, C, D). Let $X_1, X_2, \ldots$ be a sequence of four state i.i.d. trials taking values in the set $S = \{A, B, C, D\}$ of four symbols with probability $P(A) = P_a$, $P(B) = P_b$, $P(C) = P_c$ and $P(D) = P_d$, respectively. In this paper, we obtain exact formulae for the probability distribution function for runs of B's the discrete distribution of order k, longest run statistics, shortest run statistics, waiting time distribution and the distribution of run lengths.

Keywords: runs and patterns, multi-state trials, discrete distribution of order k, waiting time distribution, distribution of run length, longest run, shortest run, DNA sequence.

1 Introduction

Runs and run related statistics have been intensively studied in the literature due to the wide range of applications in various areas including statistics (e.g. hypothesis testing), engineering (e.g. system reliability, health services monitoring and quality control), molecular biology and bioinformatics (e.g. population genetics and DNA sequence homology), physics, psychology, radar astronomy, computer science (e.g. encoding/decoding and transmission of digital information) and finance (e.g. financial engineering, risk analysis and prediction). During the past few decades up to recently, the significant progress on runs and related statistics has been nicely surveyed in Balakrishnan, N. and Koutras, M. V. (2003) as well as in Fu, J. C. and Lou, W. W. (2003) and references therein. Furthermore, there are various more recent contributions on the topic such as Arapis, A. N., Makri, F. S. and Psillakis, Z. M. (2018), Eryilmaz, S. (2018), Kong, Y. (2019), Makri, F. S., Psillakis, Z. M. and Arapis, A. N. (2019), and Aki, S. (2019).

There are two main types of problems concerning runs and related statistics:

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    <u>Runs and Patterns in Probability: Selected Papers</u> Anant P. Godbole,Stavros G. Papastavridis,1994-04-30 The Probability Theory of Patterns and Runs has had a long and distinguished history starting with the work of de Moivre in the 18th century and that of von Mises in the early 1920 s and continuing with the renewal theoretic results in Feller s classic text An Introduction to Probability Theory and its Applications Volume 1 It is worthwhile to note in particular that de Moivre in the third edition of The Doctrine of Chances 1756 reprinted by Chelsea in 1967 pp 254 259 provides the generating function for the waiting time for the appearance of k consecutive successes During the 1940 s statisticians such as Mood Wolfowitz David and Mosteller studied the distribution theory both exact and asymptotic of run related statistics thereby laying the foundation for several exact run tests In the last two decades or so the theory has seen an impressive re emergence primarily due to important developments in Molecular Biology but also due to related research thrusts in Reliability Theory Distribution Theory Combinatorics and Statistics **Runs and Patterns in Probability: Selected Papers** Anant P. Godbole,Stavros G. Papastavridis,2013-05-14 The Probability Theory of Patterns and Runs has had a long and distinguished history starting with the work of de Moivre in the 18th century and that of von Mises in the early 1920 s and continuing with the renewal theoretic results in Feller s classic text An Introduction to Probability Theory and its Applications Volume 1 It is worthwhile to note in particular that de Moivre in the third edition of The Doctrine of Chances 1756 reprinted by Chelsea in 1967 pp 254 259 provides the generating function for the waiting time for the appearance of k consecutive successes During the 1940 s statisticians such as Mood Wolfowitz David and Mosteller studied the distribution theory both exact and asymptotic of run related statistics thereby laying the foundation for several exact run tests In the last two decades or so the theory has seen an impressive re emergence primarily due to important developments in Molecular Biology but also due to related research thrusts in Reliability Theory Distribution Theory Combinatorics and Statistics **Statistical Advances in Biosciences and Bioinformatics** International Biometric Society. Indian Region. Conference,2006 Papers presented at the conference held during 23 27 Nov 2003 at Banaras Hindu University Varanasi **Advances in Combinatorial Methods and Applications to Probability and Statistics** N. Balakrishnan,2012-12-06 Sri Gopal Mohanty has made pioneering contributions to lattice path counting and its applications to probability and statistics This is clearly evident from his lifetime publications list and the numerous citations his publications have received over the past three decades My association with him began in 1982 when I came to McMaster Univer sity Since then I have been associated with him on many different issues at professional as well as cultural levels I have benefited greatly from him on both these grounds I have enjoyed very much being his colleague in the statistics group here at McMaster University and also as his friend While I admire him for his honesty sincerity and dedication I appreciate very much his kindness modesty and broad mindedness Aside from our common interest in mathematics and statistics we both have great love for Indian classical music and dance We have spent numerous many

different subjects associated with the Indian music and hours discussing dance I still remember fondly the long drive to Amherst Massachusetts I had a few years ago with him and his wife Shantimayee and all the hearty discussions we had during that journey Combinatorics and applications of combinatorial methods in probability and statistics has become a very active and fertile area of research in the recent past **Mathematical Constants** Steven R. Finch,2003-08-18 Steven Finch provides 136 essays each devoted to a mathematical constant or a class of constants from the well known to the highly exotic This book is helpful both to readers seeking information about a specific constant and to readers who desire a panoramic view of all constants coming from a particular field for example combinatorial enumeration or geometric optimization Unsolved problems appear virtually everywhere as well This work represents an outstanding scholarly attempt to bring together all significant mathematical constants in one place **Stochastic Processes: Modeling and Simulation** D N Shanbhag,Calyampudi Radhakrishna Rao,2003-02-24 This sequel to volume 19 of Handbook on Statistics on Stochastic Processes Modelling and Simulation is concerned mainly with the theme of reviewing and in some cases unifying with new ideas the different lines of research and developments in stochastic processes of applied flavour This volume consists of 23 chapters addressing various topics in stochastic processes These include among others those on manufacturing systems random graphs reliability epidemic modelling self similar processes empirical processes time series models extreme value therapy applications of Markov chains modelling with Monte Carlo techniques and stochastic processes in subjects such as engineering telecommunications biology astronomy and chemistry particular with modelling simulation techniques and numerical methods concerned with stochastic processes The scope of the project involving this volume as well as volume 19 is already clarified in the preface of volume 19 The present volume completes the aim of the project and should serve as an aid to students teachers researchers and practitioners interested in applied stochastic processes *CRC Concise Encyclopedia of Mathematics* Eric W. Weisstein,2002-12-12 Upon publication the first edition of the CRC Concise Encyclopedia of Mathematics received overwhelming accolades for its unparalleled scope readability and utility It soon took its place among the top selling books in the history of Chapman Hall CRC and its popularity continues unabated Yet also unabated has been the d **Identification of Dynamical Systems with Small Noise** Yury A. Kutoyants,2012-12-06 Small noise is a good noise In this work we are interested in the problems of estimation theory concerned with observations of the diffusion type process Xo Xo 0 t T 0 1 where W is a standard Wiener process and St is some nonanticipative smooth t function By the observations X X 0 t T of this process we will solve some t of the problems of identification both parametric and nonparametric If the trend S is known up to the value of some finite dimensional parameter St X St X where E e c Rd then we have a parametric case The nonparametric problems arise if we know only the degree of smoothness of the function St X 0 t T with respect to time t It is supposed that the diffusion coefficient c is always known In the parametric case we describe the asymptotical properties of maximum likelihood MLE Bayes BE and minimum distance MDE estimators as c 0 and in the

nonparametric situation we investigate some kernel type estimators of unknown functions say StO O t T The asymptotic in such problems of estimation for this scheme of observations was usually considered as T 00 because this limit is a direct analog to the traditional limit n 00 in the classical mathematical statistics of i i d observations The limit c 0 in 0 1 is interesting for the following reasons *Optimal Reliability Modeling* Way Kuo,Ming J. Zuo,2003-02-17 Promotes better ways to diagnose maintain and improve existing systems Existing reliability evaluation models are examined with respect to today s complicated engineering systems that have hundreds of thousands of integrated component designs <u>Random Evolutions and Their Applications</u> Anatoly Swishchuk,2012-12-06 The main purpose of this handbook is to summarize and to put in order the ideas methods results and literature on the theory of random evolutions and their applications to the evolutionary stochastic systems in random media and also to present some new trends in the theory of random evolutions and their applications In physical language a random evolution RE is a model for a dynamical sys tem whose state of evolution is subject to random variations Such systems arise in all branches of science For example random Hamiltonian and Schrodinger equations with random potential in quantum mechanics Maxwell s equation with a random refractive index in electrodynamics transport equations associated with the trajec tory of a particle whose speed and direction change at random etc There are the examples of a single abstract situation in which an evolving system changes its mode of evolution or law of motion because of random changes of the environment or in a medium So in mathematical language a RE is a solution of stochastic operator integral equations in a Banach space The operator coefficients of such equations depend on random parameters Of course in such generality our equation includes any homogeneous linear evolving system Particular examples of such equations were studied in physical applications many years ago A general mathematical theory of such equations has been developed since 1969 the Theory of Random Evolutions *Limit Theory for Mixing Dependent Random Variables* Lin Zhengyan,Lu Chuanrong,1997-07-31 For many practical problems observations are not independent In this book limit behaviour of an important kind of dependent random variables the so called mixing random variables is studied Many profound results are given which cover recent developments in this subject such as basic properties of mixing variables powerful probability and moment inequalities weak convergence and strong convergence approximation limit behaviour of some statistics with a mixing sample and many useful tools are provided Audience This volume will be of interest to researchers and graduate students in the field of probability and statistics whose work involves dependent data variables *Random Fields and Stochastic Partial Differential Equations* Y. Rozanov,2013-04-17 This book considers some models described by means of partial dif ferential equations and boundary conditions with chaotic stochastic disturbance In a framework of stochastic Partial Differential Equa tions an approach is suggested to generalize solutions of stochastic Boundary Problems The main topic concerns probabilistic aspects with applications to well known Random Fields models which are representative for the corresponding stochastic Sobolev spaces The term stochastic in general indicates

involvement of appropriate random elements It assumes certain knowledge in general Analysis and Probability Hilbert space methods Schwartz distributions Fourier transform I A very general description of the main problems considered can be given as follows Suppose we are considering a random field in a region T Rd which is associated with a chaotic stochastic source by means of the differential equation in T A typical chaotic source can be represented by an appropri ate random field with independent values i e generalized random function cp TJ cp E C T with independent random variables cp fJ for any test functions cp with disjoint supports The property of having independent values implies a certain roughness of the ran dom field which can only be treated functionally as a very irregular Schwarz distribution With the lack of a proper development of non linear analyses for generalized functions let us limit ourselves to the 1 For related material see for example J L Lions E

Asymptotic Theory of Nonlinear Regression A.A. Ivanov,2013-04-17 Let us assume that an observation Xi is a random variable r v with values in 1 1 1R1 8 and distribution Pi 1R1 is the real line and 8 is the cr algebra of its Borel subsets Let us also assume that the unknown distribution Pi belongs to a 1 certain parametric family Pi E e We call the triple i 1R1 8 Pi E e a statistical experiment generated by the observation Xi n We shall say that a statistical experiment n lRn 8 P E e is the product of the statistical experiments i i 1 n if PO P X X P IRn 1 n n is the n dimensional Euclidean space and 8 is the cr algebra of its Borel subsets In this manner the experiment n is generated by n independent observations X X1 Xn In this book we study the statistical experiments n generated by observations of the form j 1 n 0 1 Xj g j cj c c In 0 1 g j is a non random function defined on e where e is the closure in IRq of the open set e IRq and C j are independent r v s with common distribution function dJ P not depending on   Contemporary Trends in Accounting, Finance and Financial Institutions Taufiq Choudhry,Jacek Mizerka,2018-03-28 This book gathers the proceedings of the ICAFFI International Conference on Accounting Finance and Financial Institutions The main topics addressed include corporate finance financial markets and asset pricing empirical finance taxation financial risk management international finance financial econometrics financial reporting and accounting standards managerial accounting measuring financial performance accounting information systems and current issues in accounting and finance in emerging and other markets Presenting both cutting edge research and a broad set of methods and combining practical and theoretical perspectives the book offers a valuable resource for researchers practitioners and regulators alike   Gaussian Random Functions M.A. Lifshits,2013-03-09 It is well known that the normal distribution is the most pleasant one can even say an exemplary object in the probability theory It combines almost all conceivable nice properties that a distribution may ever have symmetry stability indecomposability a regular tail behavior etc Gaussian measures the distributions of Gaussian random functions as infinite dimensional analogues of tht

Limit Theorems for Random Fields with Singular Spectrum Nikolai Leonenko,1999-02-28 This book presents limit theorems for nonlinear functionals of random fields with singular spectrum on the basis of various asymptotic expansions This book will be of interest to mathematicians who use random fields in engineering or other applications   *Information*

Systems Architecture and Technology: Proceedings of 37th International Conference on Information Systems Architecture and Technology – ISAT 2016 – Part IV Zofia Wilimowska,Leszek Borzemski,Adam Grzech,Jerzy Świątek,2016-09-17 This four volume set of books constitutes the proceedings of the 2016 37th International Conference Information Systems Architecture and Technology ISAT or ISAT 2016 for short held on September 18 20 2016 in Karpacz Poland The conference was organized by the Department of Management Systems and the Department of Computer Science Wroc aw University of Science and Technology Poland The papers included in the proceedings have been subject to a thorough review process by highly qualified peer reviewers The accepted papers have been grouped into four parts Part I addressing topics including but not limited to systems analysis and modeling methods for managing complex planning environment and insights from Big Data research projects Part II discoursing about topics including but not limited to Web systems computer networks distributed computing and multi agent systems and Internet of Things Part III discussing topics including but not limited to mobile and Service Oriented Architecture systems high performance computing cloud computing knowledge discovery data mining and knowledge based management Part IV dealing with topics including but not limited to finance logistics and market problems and artificial intelligence methods   Geometric Sums: Bounds for Rare Events with Applications Vladimir V. Kalashnikov,2013-04-17 This book reviews problems associated with rare events arising in a wide range of circumstances treating such topics as how to evaluate the probability an insurance company will be bankrupted the lifetime of a redundant system and the waiting time in a queue Well grounded unique mathematical evaluation methods of basic probability characteristics concerned with rare events are presented which can be employed in real applications as the volume also contains relevant numerical and Monte Carlo methods The various examples tables figures and algorithms will also be appreciated Audience This work will be useful to graduate students researchers and specialists interested in applied probability simulation and operations research   *Asymptotic Behaviour of Linearly Transformed Sums of Random Variables* V.V. Buldygin,Serguei Solntsev,2012-12-06 Limit theorems for random sequences may conventionally be divided into two large parts one of them dealing with convergence of distributions weak limit theorems and the other with almost sure convergence that is to say with asymptotic prop erties of almost all sample paths of the sequences involved strong limit theorems Although either of these directions is closely related to another one each of them has its own range of specific problems as well as the own methodology for solving the underlying problems This book is devoted to the second of the above mentioned lines which means that we study asymptotic behaviour of almost all sample paths of linearly transformed sums of independent random variables vectors and elements taking values in topological vector spaces In the classical works of P Levy A Ya Khintchine A N Kolmogorov P Hartman A Wintner W Feller Yu V Prokhorov and M Loeve the theory of almost sure asymptotic behaviour of increasing scalar normed sums of independent random vari ables was constructed This theory not only provides conditions of the almost sure convergence of series of independent random variables but also studies

different ver sions of the strong law of large numbers and the law of the iterated logarithm One should point out that even in this traditional framework there are still problems which remain open while many definitive results have been obtained quite recently   Stochastic Processes: General Theory Malempati M. Rao,2013-03-14 Stochastic Processes General Theory starts with the fundamental existence theorem of Kolmogorov together with several of its extensions to stochastic processes It treats the function theoretical aspects of processes and includes an extended account of martingales and their generalizations Various compositions of quasi or semi martingales and their integrals are given Here the Bochner boundedness principle plays a unifying role a unique feature of the book Applications to higher order stochastic differential equations and their special features are presented in detail Stochastic processes in a manifold and multiparameter stochastic analysis are also discussed Each of the seven chapters includes complements exercises and extensive references many avenues of research are suggested The book is a completely revised and enlarged version of the author s Stochastic Processes and Integration Noordhoff 1979 The new title reflects the content and generality of the extensive amount of new material Audience Suitable as a text reference for second year graduate classes and seminars A knowledge of real analysis including Lebesgue integration is a prerequisite

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