From Stochastic Calculus to Mathematical Finance

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From Stochastic Calculus to Mathematical Finance

The Shiryaev Festschrift

With 15 Figures

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To Albert Shiryaev with love, admiration and respect

Preface

This volume contains a collection of articles dedicated to Albert Shiryaev on his 70th birthday. The majority of contributions are written by his former students, co-authors, colleagues and admirers strongly influenced by Albert's scientific tastes as well as by his charisma. We believe that the papers of this Festschrift reflect modern trends in stochastic calculus and mathematical finance and open new perspectives of further development in these fascinating fields which attract new and new researchers. Almost all papers of the volume were presented by the authors at The Second Bachelier Colloquium on Stochastic Calculus and Probability, Metabief, France, January 9-15, 2005.

Ten contributions deal with stochastic control and its applications to economics, finance, and information theory.

The paper by V. Arkin and A. Slastnikov considers a model of optimal choice of an instant to launch an investment in the setting that permits the inclusion of various taxation schemes; a closed form solution is obtained. M.H.A. Davis addresses the problem of hedging in a "slightly" incomplete financial market using a utility maximization approach. In the case of the exponential utility, the optimal hedging strategy is computed in a rather explicit form and used further for a perturbation analysis in the case where the option underlying and traded assets are highly correlated.

The paper by G. Di Masi and L. Stettner is devoted to a comparison of infinite horizon portfolio optimization problems with different criteria, namely, with the risk-neutral cost functional and the risk-sensitive cost functional dependent on a sensitivity parameter $\gamma < 0$. The authors consider a model where the price processes are conditional geometric Brownian motions, and the conditioning is due to economic factors. They investigate the asymptotics of the optimal solutions when γ tends to zero. An optimization problem for a one-dimensional diffusion with long-term average criterion is considered by A. Jack and M. Zervos; the specific feature is a combination of absolute continuous control of the drift and an impulsive way of repositioning the system state.

Yu. Kabanov and M. Kijima investigate a model of corporation which combines investments in the development of its own production potential with investments in financial markets. In this paper the authors assume that the investments to expand production have a (bounded) intensity. In contrast to this approach, H. Pham considers a model with stochastic production capacity where accumulated investments form an increasing process which may have jumps. Using techniques of viscosity solutions for HJB equations, he provides an explicit expression for the value function.

P. Katyshev proves an existence result for the optimal coding and decoding of a Gaussian message transmitted through a Gaussian information channel with feedback; the scheme considered is more general than those available in the literature.

I. Sonin and E. Presman describe an optimal behavior of a female decision-maker performing trials along randomly evolving graphs. Her goal is to select the best order of trials and the exit strategy. It happens that there is a kind of Gittins index to be maximized at each step to obtain the optimal solution.

M. Rásonyi and L. Stettner consider a classical discrete-time model of arbitrage-free financial market where an investor maximizes the expected utility of the terminal value of a portfolio starting from some initial wealth. The main theorem says that if the value function is finite, then the optimal strategy always exists.

The paper by I. Sonin deals with an elimination algorithm suggested earlier by the author to solve recursively optimal stopping problems for Markov chains in a denumerable phase space. He shows that this algorithm and the idea behind it can be applied to solve discrete versions of the Poisson and Bellman equations.

In the contribution by five authors — O. Barndorff-Nielsen, S. Graversen, J. Jacod, M. Podolski, and N. Sheppard — a concept of bipower variation process is introduced as a limit of a suitably chosen discrete-time version. The main result is that the difference between the approximation and the limit, appropriately normalizing, satisfies a functional central limit theorem.

J. Carcovs and J. Stoyanov consider a two-scale system described by ordinary differential equations with randomly modulated coefficients and address questions on its asymptotic stability properties. They develop an approach based on a linear approximation of the original system via the averaging principle.

A note of A. Cherny summarizes relationships with various properties of martingale convergence frequently discussed at the A.N. Shiryaev seminar. In another paper, co-authored with M. Urusov, A. Cherny, using a concept of separating times makes a revision of the theory of absolute continuity and singularity of measures on filtered space (constructed, to a large extent by A.N. Shiryaev, J. Jacod and their collaborators). The main contribution consists in a detailed analysis of the case of one-dimensional distributions.

B. Delyon, A. Juditsky, and R. Liptser establish a moderate deviation principle for a process which is a transformation of a homogeneous ergodic Markov

chain by a Lipshitz continuous function. The main tools in their approach are the Poisson equation and stochastic exponential.

A. Guschin and D. Zhdanov prove a minimax theorem in a statistical game of statistician versus nature with the f-divergence as the loss functional. The result generalizes a result of Haussler who considered as the loss functional the Kullback–Leibler divergence.

Yu. Kabanov, Yu. Mishura, and L. Sakhno look for an analog of Harrison–Pliska and Dalang–Morton–Willinger no-arbitrage criteria for random fields in the model of Cairolli–Walsh. They investigate the problem for various extensions of martingale property for the case of two-parameter processes.

Several studies are devoted to processes with jumps, which theory seems to be interested from the point of view of financial applications.

To this class belong the contributions by J. Fajardo and E. Mordecki (pricing of contingent claims depending on a two-dimensional Lévy process) and by D. Gasbarra, E. Valkeila, and L. Vostrikova where an enlargement of filtration (important, for instance, to model an insider trading) is considered in a general framework including the enlargement of filtration spanned by a Lévy process.

The paper by H.-J. Engelbert, V. Kurenok, and A. Zalinescu treats the existence and uniqueness for the solution of the Skorohod reflection problem for a one-dimensional stochastic equation with zero drift and a measurable coefficient in the noise term. The problem looks exactly like the one considered previously by W. Schmidt. The essential difference is that instead of the Brownian motion, the driving noise is now any symmetric stable process of index $\alpha \in]0, 2]$.

C. Klüppelberg, A. Lindner, and R. Maller address the problem of modelling of stochastic volatility using an approach which is a natural continuous-time extension of the GARCH process. They compare the properties of their model with the model (suggested earlier by Barndorff-Nielsen and Sheppard) where the squared volatility is a Lévy driven Ornstein–Uhlenbeck process.

A survey on a variety of affine stochastic volatility models is given in a didactic note by I. Kallsen.

The note by R. Liptser and A. Novikov specifies the tail behavior of distribution of quadratic characteristics (and also other functionals) of local martingales with bounded jumps extending results known previously only for continuous uniformly integrable martingales.

In their extensive study, S. Lototsky and B. Rozovskii present a newly developed approach to stochastic differential equations. Their method is based on the Cameron–Martin version of the Wiener chaos expansion and provides a unified framework for the study of ordinary and partial differential equations driven by finite- or infinite-dimensional noise. Existence, uniqueness, regularity, and probabilistic representation of generalized solutions are established for a large class of equations. Applications to non-linear filtering of diffusion processes and to the stochastic Navier–Stokes equation are also discussed.

The short contribution by M. Mania and R. Tevzadze is motivated by financial applications, namely, by the problem of how to characterize variance-optimal martingale measures. To this aim the authors introduce an exponential backward stochastic equation and prove the existence and uniqueness of its solution in the class of BMO-martingales.

The paper by J. Oblój and M. Yor gives, among other results, a complete characterization of the "harmonic" functions $H(x, \bar{x})$ for two-dimensional processes $(N, \bar{N})$ where N is a continuous local martingale and $\bar{N}$ is its running maximum, i.e. $\bar{N}_t := \sup_{s \le t} N_t$. Resulting (local) martingales are used to find the solution to the Skorohod embedding problem. Moreover, the paper contains a new interesting proof of the classical Doob inequalities.

G. Peskir studies the Kolmogorov forward PDE corresponding to the solution of non-homogeneous linear stochastic equation (called by the author the Shiryaev process) and derives an integral representation for its fundamental solution. Note that this equation appeared first in 1961 in a paper by Shiryaev in connection with the quickest detection problem. In statistical literature one can meet also the "Shiryaev–Roberts procedure" (though Roberts worked only with a discrete-time scheme).

The note by A. Veretennikov contains inequalities for mixing coefficients for a class of one-dimensional diffusions implying, as a corollary, that processes of such type may have long-term dependence and heavy-tail distributions.

N. Bingham and R. Schmidt give a survey of modern copula-based methods to analyze distributional and temporal dependence of multivariate time series and apply them to an empirical studies of financial data.

Yuri Kabanov
Robert Liptser
Jordan Stoyanov

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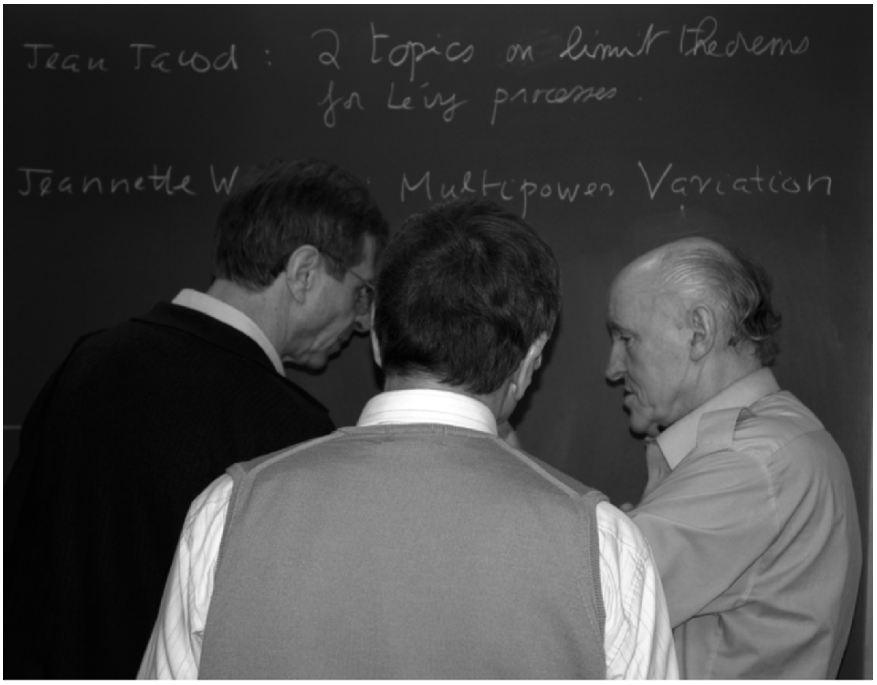
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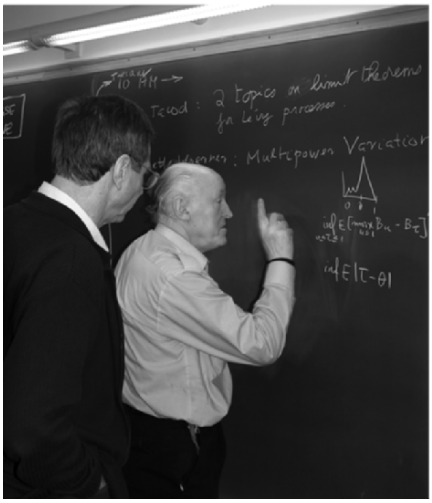
Multipower Variation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Jacod : 2 topics on limit theorems
for Lévy processes
: Multipower Variation

Albert SHIRYAEV

Albert Shiryaev, outstanding Russian mathematician, celebrated his 70th birthday on October 12, 2004. The authors of this biographic note, his former students and collaborators, have the pleasure and honour to recollect briefly several facts of the exciting biography of this great man whose personality influenced them so deeply.

Albert's choice of a mathematical career was not immediate or obvious. In view of his interests during his school years, he could equally well have become a diplomat, as his father was, or a rocket engineer as a number of his relatives were. Or even a ballet dancer or soccer player: Albert played right-wing in a local team. However, after attending the mathematical evening school at Moscow State University, he decided – definitely – mathematics. Graduating with a Gold Medal, Albert was admitted to the celebrated *mechmat*, the Faculty of Mechanics and Mathematics, without taking exams, just after an interview. In the 1950s and 1960s this famous faculty was at the zenith of its glory: rarely in history have so many brilliant mathematicians, professors and students – real stars and superstars – been concentrated in one place, at the five central levels of the impressive university building dominating the Moscow skyline. One of the most prestigious chairs, and the true heart of the faculty, was Probability Theory and Mathematical Statistics, headed by A.N. Kolmogorov. This was Albert's final choice after a trial year at the chair of Differential Equations.

In a notice signed by A.N. Kolmogorov, then the dean of the faculty, we read: "Starting from the fourth year A. Shiryaev, supervised by R.L. Dobrushin, studied probability theory. His subject was nonhomogeneous composite Markov chains. He obtained an estimate for the variance of the sum of random variables forming a composite Markov chain, which is a substantial step towards proving a central limit theorem for such chains. This year A. Shiryaev has shown that the limiting distribution, if it exists, is necessarily infinitely divisible".

Besides mathematics, what was Albert's favourite activity? Sport, of course. He switched to downhill skiing, rather exotic at that time, and it

became a lifetime passion. Considering the limited facilities available in Central Russia and the absence of equipment, his progress was simply astonishing: Albert participated in competitions of the 2nd Winter Student Games in Grenoble and was in the first eight in two slalom events! Since then he has done much for the promotion of downhill skiing in the country, and even now is proud to compete successfully with much younger skiers. Due to him, skiing became the most popular sport amongst Soviet probabilists.

Albert's mathematical talent and human qualities were noticed by Kolmogorov who became his spiritual father. Kolmogorov offered Albert and his friend V. Leonov positions in the department he headed at the Steklov Mathematical Institute, where the two of them wrote their well-known paper of 1959 on computation of semi-invariants.

In Western surveys of Soviet mathematics it is often noted that, unlike European and American schools, in the Soviet Union it was usual not to limit the research interests to pure mathematics. Many top Russian mathematicians renowned for their great theoretical achievements have also worked fruitfully on the most applied, but practically important, problems arising in natural and social sciences and engineering. The leading example was Kolmogorov himself, with his enormous range of contributions from turbulence to linguistics.

Kolmogorov introduced Albert to the so-called "disorder" or "quickest detection" problem. This was a major theoretical challenge but also had important applications in connection with the Soviet Union's air defence system. In a series of papers the young scientist developed, starting from 1960, a complete theory of optimal stopping of Markov processes in discrete and continuous time, summarized later in his well-known monograph *Statistical Sequential Analysis: Optimal Stopping Rules*, published in successive editions in Russian (1969, 1977) and English (1972, 1978). It is worth noting that the passage to continuous-time modelling turned out to be a turning point in the application of Ito calculus. A firm theoretical foundation built by Albert gave a rigorous treatment, replacing the heuristic arguments employed in early studies in electronic engineering, which sometimes led to incorrect results. The stochastic differential equations (known as Shiryaev's equations) describing the dynamics of the sufficient statistics were the basis of nonlinear filtering theory. The techniques used to determine optimal stopping rules revealed deep relations with a moving boundary problem for the second-order PDEs (known as the Stefan problem). Shiryaev's pioneering publications and his monograph are cited in almost every publication on sequential analysis and optimal stopping, showing the deep impact of his studies.

The authors of this note were Albert's students at the end of sixties, charmed by his energy, deep understanding of random processes, growing erudition, and extreme feeling for innovative approaches and trends. His seminar, first taking place at Moscow State University, at the Laboratory of Statistical Methods (organized and directed by A.N. Kolmogorov who invited Albert to be a leader of one of his teams) and hosted afterwards at Steklov Institute,

became more and more popular as a prestigious place for exchanging new ideas and presenting current research. At that period Albert concentrated his efforts on nonlinear filtering, prediction and smoothing of partially observed processes. Jointly with his colleagues and students, Shiryaev created a general theory for diffusion-type processes (stochastic partial differential equation for the filtering density) and for Markov processes with countable set of states, extending the well-known Kalman–Bucy filtering equation to the conditionally Gaussian case. His students were working on topics including stochastic differential equations, anticipating stochastic calculus, and point processes.

Naturally, these studies were not restricted to purely theoretical exercises but followed a quest for possible applications, such as optimal control with incomplete data, optimal coding/decoding in noisy information channels, statistical inference for diffusion processes, and even using the noise-free Kalman filter for solving ill-posed systems of linear algebraic equations. An account of these researches can be found in the book *Statistics of Random Processes*, written with Robert Liptser. This book has been appreciated by generations of scholars: it first appeared in Russian in 1974 while the 2nd English edition (in two volumes) appeared in 2000!

The end of the seventies was a revolution in the theory of random processes: the construction of stochastic calculus (i.e. theory of semimartingales) as a unified theory was completed. It combines the classical Ito calculus, jump processes and discrete-time models. This was done by the efforts of the French and Soviet schools, especially that of P.-A. Meyer (with his fundamental works on the general theory of processes and stochastic integration), J. Jacod, A.V. Skorohod, and A. Shiryaev. Symbolically, two prestigious plenary talks in Probability Theory at the International Mathematical Congress in Helsinki (1978) were given by representatives of these schools (a scarce event because of the historical dominance of classical fields!). The talk by Claude Dellacherie was an announcement that the calculus had achieved its most general form: a process with respect to which one can integrate while preserving natural properties must be a semimartingale. The talk by Albert Shiryaev was about necessary and sufficient conditions for absolute continuity of measures corresponding to semimartingales or, more generally, of measures on a filtered probability space, results whose importance was fully revealed much later, in the context of financial modelling.

At the beginning of the eighties Albert launched another ambitious project: functional limit theorems for semimartingales as an application of stochastic calculus to the classical branch of probability theory. He was one of the first who understood the importance of the canonical decomposition and triplets of predictable characteristics introduced by J. Jacod in an analogy with the Lévy–Khinchine formula. Convergence of triplets implies convergence of distributions: the observation permitting to put many traditional limit theorems, even the ones for models with dependent summands, into a much more general context of weak convergence of distributions of semimartingales. These studies resulted in two fundamental monographs, *The Theory of Martingales* (1986)

and *Limit Theorems for Stochastic Processes* (1987) co-authored, respectively, with R. Liptser and J. Jacod.

It was observed by Harrison and Pliska in 1981 that stochastic calculus is tailor-made for financial modelling. On the other hand, pricing of American options is reduced to a solution of an optimal stopping problem. So it is not surprising that Albert, just starting to work in mathematical finance, immediately contributed to this new field by a number of interesting results (see his works with L. Shepp, D. Kramkov, M. Jeanblanc, M. Yor and many others). The true surprise was perhaps a voluminous book written in record time (just in two years): *Essentials of Stochastic Finance: Facts, Models, Theory* (1998), reprinted annually because of a regularly exhausted stock.

What is the best textbook in probability for mathematical students? There are many; but our favourite is *Probability* by A.N. Shiryaev (editions in Russian, English, German,...) which can be considered as an elementary introduction into the technology of stochastic calculus containing a number of rather recent results for discrete-time models. The latest valuable addendum to this textbook is a volume of selected problems.

Shiryaev's charisma always attracted students who never regretted the choice of their supervisor as "doctor father". More than fifty scholars are proud to be his PhD-students, and they are working worldwide. Thousands followed his brilliant lectures at the Moscow State University where he has been Professor since 1970 and the Head of the Chair of Probability Theory since 1996.

Albert was engaged in editorial activity from his first days at the Steklov Institute. He was charged by Kolmogorov with serving as an assistant for the newly established *Probability Theory and Its Applications* (now subtitled 'The Kolmogorov Journal'); he was the deputy of the Editor Yu. V. Prohorov from 1988. He has served on the editorial boards of a long list of distinguished mathematical, statistical, and mathematical finance journals, and is, for example, currently a co-editor of *Finance and Stochastics*. Throughout his career he has championed in a very active way the traditions of good mathematical literature, and been a severe critic of sloppily written texts.

Among his publishing activities we should also mention his recent great efforts in the promotion of Kolmogorov's legacy: three volumes of inestimable historical documents including a diary, correspondence, bibliography and memoirs. Albert is especially proud of the production of a DVD with a documentary about the life of his great teacher and his scientific heritage.

A further aspect of his work has been enthusiastic participation in the organization of memorable international meetings and large-scale events strongly influencing the life of the mathematical community: the Soviet–Japanese Symposia in Probability Theory (starting from 1969), the First World Congress of the Bernoulli Society (Tashkent, 1986), the Kolmogorov Centenary Conference (Moscow, 2003), and many others.

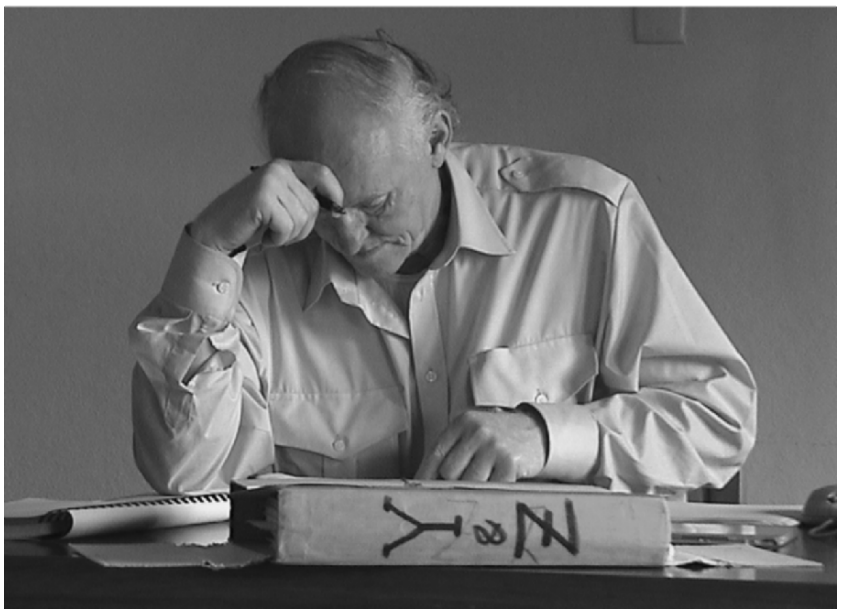
Albert's mathematical achievements and services to the mathematical community have been recognized in a series of international honours and awards, some of which are listed below.

On October 12, 2004, Albert Shiryaev tuned seventy years old, but he remains young as never before.

Albert N. Shiryaev: Honours and Awards

Honorary Fellow of the Royal Statistical Society (1985).
Member of the Academia Europea (1990).
Correspondent member of the Russian Academy of Sciences (1997).
Member of the New York Academy of Science (1997).
President of the Bernoulli Society (1989-1991).
President of the Russian Actuarial Society (1994-1998).
President of the Bachelier Finance Society (1998-1999).
Markov prize winner (1974), Kolmogorov prize winner (1994).
Humboldt Research Award (1996).
Doctor Rerum Naturalium Honoris Causa Albert-Ludwig-Universität Freiburg-im-Bresgau (2000).
Professor Honoris Causa of the Amsterdam University (2002).


Albert Shiryaev



Publications of A.N. Shiryaev

I. Monographs and textbooks

1. *Additional Chapters of Probability Theory.* (Russian) Moscow: Moscow Univ. Press, 1968, 207 pp.
2. *Statistical Sequential Analysis: Optimal Stopping Rules.* (Russian) Moscow: "Nauka", 1969. 231 pp.
3. *Stochastic Processes.* (Russian) Moscow: Moscow Univ. Press, 1972, 241 pp.
4. *Statistical Sequential Analysis. Optimal Stopping Rules.* (Engl. transl. of [2].) Transl. Math. Monogr., 38. Providence, RI: Amer. Math. Soc., 1973. iv+174 pp.
5. *Probability, Statistics, Random Processes. I.* (Russian) Moscow: Moscow Univ. Press, 1973. 204 pp.
6. *Probability, statistics, random processes. II.* (Russian) Moscow: Moscow Univ. Press, 1974. 224 pp.
7. *Statistics of Random Processes. Nonlinear Filtering and Related Problems.* (Russian) Probab. Theory Math. Statist., 15. Moscow: "Nauka", 1974. 696 pp.
8. *Statistical Sequential Analysis. Optimal Stopping Rules.* 2nd ed., revised. (Russian) Moscow: "Nauka", 1976. 272 pp.
9. *Statistics of Random Processes. I. General Theory. II. Applications.* (Engl. transl. of [7].) Appl. Math., 5, 6. New York–Heidelberg: Springer-Verlag, 1977. x+394 pp.; 1978. x+339 pp. (with R. Sh. Liptser).
10. *Optimal Stopping Rules.* (Engl. transl. of [8].) Appl. Math., 8. New York–Heidelberg: Springer-Verlag, 1978. x+217 pp.
11. *Probability.* (Russian) Moscow: "Nauka", 1980. 576 pp.
12. *Statistics of Random Processes. Nonlinear Filtration and Related Questions.* (Polish transl. of [7].) Warsaw: Państwowe Wydawnictwo Naukowe (PWN), 1981. 680 pp. (with R. Sh. Liptser).
13. *Probability.* (Engl. transl. of [11].) Graduate Texts in Mathematics, 95. New York: Springer-Verlag, 1984. xi+577 pp.
14. *Contiguity and the Statistical Invariance Principle.* Stochastics Monographs, 1. New York: Gordon & Breach, 1985. viii+236 pp. (with P. E. Greenwood).
15. *Theory of Martingales.* (Russian) Probability Theory and Mathematical Statistics. Moscow: "Nauka", 1986. 512 pp. (with R. Sh. Liptser).
16. *Limit Theorems for Stochastic Processes.* Grundlehren der Mathematischen Wissenschaften, 288. Berlin: Springer-Verlag, 1987. xviii+601 pp. (with J. Jacod).

17. Wahrscheinlichkeit. (German transl. of [11].) Hochschulbucher fur Mathematik, 91. Berlin: VEB Deutscher Verlag der Wissenschaften, 1988. 592 pp.
18. *Probability.* (Russian) 2nd ed. of [11]. Moscow: "Nauka", 1989. 640 pp.
19. *Theory of Martingales.* (Engl. transl. of [15].) Math. Appl. (Soviet Ser.), 49. Dordrecht: Kluwer Acad. Publ., 1989. xiv+792 pp. (with R. Sh. Liptser).
20. *Limit theorems for stochastic processes.* Vol. 1, 2. (Russian transl. of [16].) Probab. Theory Math. Statist., 47, 48. Moscow: Fizmatlit, "Nauka", 1994. 544 pp., 368 pp. (with J. Jacod).
21. *Probability.* 2nd ed. (Engl. transl. of [18].) Graduate Texts in Mathematics, 95. New York: Springer-Verlag, 1995. xi+609 pp.
22. *Essentials of Stochastic Finance.* (Russian) Vol. I: Facts and Models. Vol. II: Theory. Moscow: "FAZIS", 1998. 1018 pp.
23. *Essentials of Stochastic Finance. Facts, Models, Theory.* (Engl. transl. of [22].) Adv. Ser. Statist. Sci. Appl. Probab., 3. River Edge, NJ: World Scientific, 1999. xvi+834 pp. Reprinted 1999, 2000, 2001, 2003.
24. *Statistical Experiments and Decision. Asymptotic Theory.* River Edge, NJ: World Scientific, 2000. xvi+281 pp. (with V. G. Spokoiny).
25. *Statistics of Random Processes.* 2nd rev. and expanded ed. of [9].) Vol. I: General Theory. Vol. II: Applications. Appl. Math. (New York), 5, 6. Berlin: Springer-Verlag, 2001. xv+427 pp., xv+402 pp. (with R. Sh. Liptser).
26. *Limit Theorems for Stochastic Processes.* 2nd expanded ed. of [16].) Grundlehren der Mathematischen Wissenschaften. 288. Berlin: Springer-Verlag, 2003. xx+661 pp.
27. *Theory of Random Processes.* (Russian) Moscow: Fizmatlit, 2003. 399 pp. (with A. V. Bulinsky).
28. *Essentials of Stochastic Finance.* (Russian) Vol. I: Facts and Models. Vol. II: Theory. 2nd corrected ed. of [22]. Moscow: "FAZIS", 2004. xxxviii+1018 pp.

II. Main scientific papers

1. A central limit theorem for complex inhomogeneous Markov chains. (Russian) *Teor. Veroyatnost. i Primenen.* 2 (1957), no. 4, 485–486; Engl. transl. in *Theory Probab. Appl.* 2 (1957), no. 4, 477–478.
2. On a method of calculation of semi-invariants. (Russian) *Teor. Veroyatnost. i Primenen.* 4 (1959), no. 3, 341–355; Engl. transl. in *Theory Probab. Appl.* 4 (1960), no. 3, 319–329 (with V. P. Leonov).
3. Some problems in the spectral theory of higher-order moments. I. (Russian) *Teor. Veroyatnost. i Primenen.* 5 (1960), no. 3, 293–313; corrections: *ibid.* no. 4; Engl. transl. in *Theory Probab. Appl.* 5 (1960), no. 3, 265–284; corrections: *ibid.* no. 4.
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6. The problem of the most rapid detection of a disturbance of a stationary regime. (Russian) *Dokl. Akad. Nauk SSSR* 138 (1961), no. 5, 1039–1042; Engl. transl. in *Soviet Math. Dokl.* 2 (1961), 795–799.
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12. On detecting of disorders in industrial processes. II. (Russian) *Teor. Veroyatnost. i Primenen.* 8 (1963), no. 4, 431–443; Engl. transl. in *Theory Probab. Appl.* 8 (1963), no. 4.
13. On conditions for ergodicity of stationary processes in terms of higher-order moments. (Russian) *Teor. Veroyatnost. i Primenen.* 8 (1963), no. 4, 470–473; Engl. transl. in *Theory Probab. Appl.* 8 (1963), no. 4, 436–439.
14. On problems of quickest detection of randomly arising effects. (Russian) *Proceedings of the IV All-Union Mathematical Congress.* Leningrad, 1964, pp. 379–383.
15. On the theory of decision functions and control of a process of observation based on incomplete information. (Russian) *Transactions of the Third Prague Conference on Information Theory, Statistical Decision Functions, Random Processes* (Liblice, 1962). 1964, pp. 657–681; Engl. transl. in *Select. Transl. Math. Statist. Probab.* 6 (1966), 162–188.
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20. A Bayesian problem of sequential search in diffusion approximation. (Russian) *Teor. Veroyatnost. i Primenen.* 10 (1965), no. 1, 192–199; Engl. transl. in *Theory Probab. Appl.* 10 (1965), no. 1, 178–186 (with R. Sh. Liptser).
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