International Encyclopedia of Statistical Science

Miodrag Lovric (Ed.)

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With 153 Figures and 91 Tables

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To my lovely wife Vesna Lovric (nee Jovandic),

and our children Tara and Andrei

Foreword by Bradley Efron

The Future of Statistics

▸ Strange, as one gets older you're expected to know more about the future.

The history of statistics as a recognized discipline divides rather neatly at 1900, the year of Karl Pearson's chi-square paper. Before then we are still close to the world of Quetelet, where huge census-level data sets are brought to bear on simple but important questions: Are there more male or female births? Is the murder rate rising? Then, as if on cue, the Twentieth Century rings in a focus on small-scale statistics. A team of intellectual giants, Fisher, Neyman, Hotelling, …, invent a theory of optimal inference, capable of wringing out every drop of collected information. The questions are still simple: Is treatment A better than treatment B? But the new methods are suited to the kinds of small data sets an individual scientist might collect.

What does this have to do with the future of statistics? Quite a bit, perhaps: the Twenty-First Century, again on cue, seems to have initiated a third statistical era. New technologies, exemplified by the microarray, permit scientists to collect their own huge data sets. But this is not a return to the age of Quetelet. The flood of data is now accompanied by a flood of questions, perhaps thousands of them, that the statistician is charged with answering together; not at all the setting Fisher et al. had in mind.

As a cruder summary of my already crude statistical history, we have

19th Century:	Large data sets, simple questions
20th Century:	Small data sets, simple questions
21st Century:	Large data sets, complex questions

The future of statistics, or at least the next large chunk of future, will be preoccupied, I believe, with problems of large-scale inference raised in our revolutionary scientific environment. For example, how should one analyze 10,000 related hypothesis tests or 100,000 correlated estimates at the same time?

Figure 1 concerns an example of large-scale inference from Singh et al. (2002): 52 prostate cancer patients and 50 normal controls have each had his genetic expression levels measured on $N = 6,033$ genes. This produces a matrix of measurements $\boldsymbol{X}$ with $N = 6,033$ rows, one for each gene, and 102 columns, one for each man: enormous by Twentieth Century standards but nothing remarkable these days. We wonder which of the genes, if any, are more active in the cancer patients.

As a first step we can compute a two-sample t-statistic t_i comparing expression levels between cancer patients and controls on gene i. For Fig. 1, each t_i has been transformed into a z-value z_i, by definition a test statistic having a standard normal distribution under the null hypothesis that gene i behaves the same in both groups,

$$H_0 : z_i \sim \mathcal{N}(0,1). \tag{1}$$

The histogram of the 6033 z_i's looks like a $\mathcal{N}(0,1)$ curve near its center, which makes sense since presumably most of the genes are *not* involved in prostate cancer etiology, but it also shows a promising excess of values in the extreme tails. For example, 49 of the z_i's exceed 3 (indicated by the hash marks) whereas the expected number is only 8.14 if all the genes follow (1). Should we report the list of 49 back to the researchers as interesting candidates for further study?

Any one of the genes is wildly significant by classical single-test standards where we would reject H_0 for $z_i > 1.96$, the two-sided .05 value. But with $N = 6,033$, the .05 Bonferroni bound requires $z_i > 4.46$, the two-sided $.05/N$ value, and only 3 of the 49 genes make the cut.

In what might be taken as a premonitory salvo of Twenty-First Century statistics, Benjamini and Hochberg (1995) proposed a different, more lenient standard for large-scale testing based on *False Discovery Rates*:

$$\mathrm{Fdr}(3) = 8.14/49 = .166 \tag{2}$$

in our case, the ratio of counts expected under null conditions to those actually observed in the interval $(3,\infty)$. Assuming independence of the z-values, they showed that a statistician who chooses to reject all z_i's in the largest interval (x,∞) such that $\mathrm{Fdr}(x)$ is less than some control level q will make an expected proportion of false discoveries no greater than q. Taking $q = .166$ for the prostate data gives $x = 3$ and suggests that 1/6 of the list of 49 are false discoveries, the other 5/6 being genuinely non-null genes: not bad odds for the prospects of further investigation.

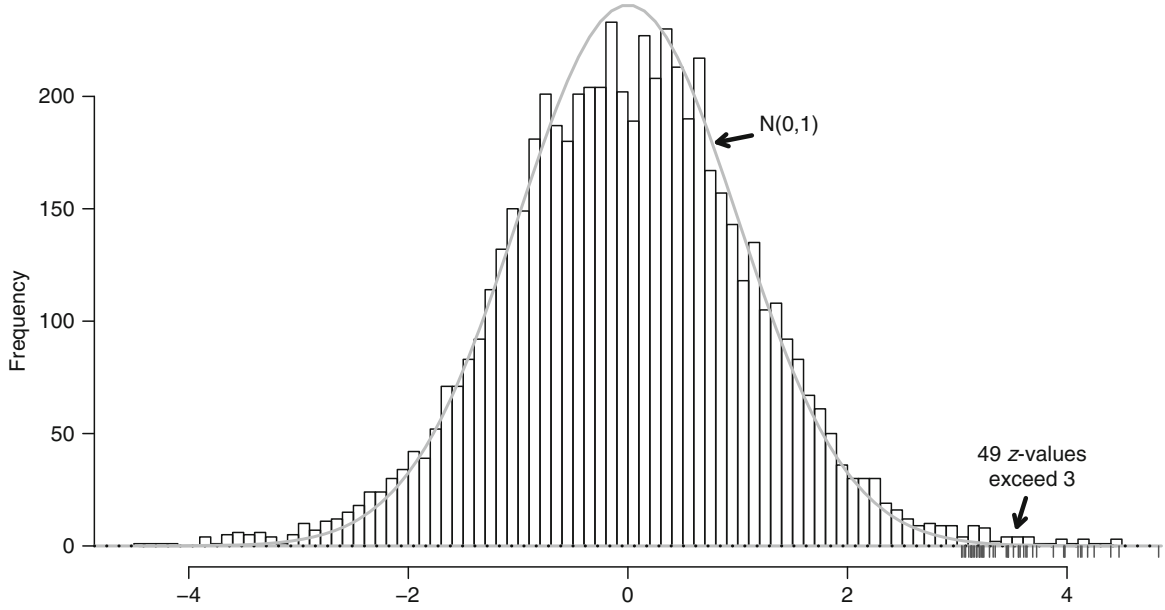

Figure 1 $N = 6{,}033$ z-values, prostate study

Controlling Fdr is fundamentally different than controlling the probability of Type I error. Now the significance of a gene that has $z_i > 3$ depends on how many others exceed 3. If there were only 10 such, instead of 49, we would have $\text{Fdr}(3) = .81$; not an encouraging prospect for the investigators.

Twentieth Century applied statistics has been very much a world of direct evidence in which each case, each gene in our example, is judged entirely on its own data. This is a world designed for frequentism, where objectivity is enforced by notions of unbiasedness, minimum variance, size and power. But large-scale data sets like that for the prostate study abound with indirect evidence: our interest in z_i is affected by all the other z_j's. I believe that the immediate future of statistical theory and practice crucially involves "learning from the experience of others," i.e., the incorporation of indirect evidence.

Bayes theorem is a perfect recipe for learning from the experience of others, and we can expect Bayesian methods to play a greater role in Twenty-First Century data analysis. Fdr theory was derived frequentistically, but it has a compelling Bayesian rationale. Assuming that the prior probability of a null case is near 1, Bayes theorem yields

$$\Pr\{\text{gene } i \text{ is null} | z_i \geq x\} \doteq F_0(x)/F(x) \qquad (3)$$

where F_0 is the probability that a null z_i exceeds x [equaling $1 - \Phi(x)$ under (1)] and $F(x)$ is the probability that a randomly selected z_i, null or not, exceeds x. Substituting the empirical cdf $\hat{F}(x)$ for the unknown $F(x)$ gets us back to definition (2); see Efron (2008). We can restate the Benjamini–Hochberg procedure in Bayesian terms: "Reject those z_i's in the largest interval (x, ∞) that has estimated Bayes null probability (3) less than q."

Indirect evidence is not the sole property of Bayesians. Tukey's phrase "borrowing strength" nicely captures the frequentist regression tactic of using nearby data points to assist in estimation at a particular point of interest. "Nearby" refers to distance in a space of relevant covariates. The explosion in data collection has brought with it an explosion in the number of covariates, often too many for standard regression techniques. A thriving industry of new methods has emerged – boosting, bagging, CART, Lasso, LARS, projection pursuit – which search to build effective regression models from subsets of the available regressors. The generic term here is *data mining*, which began as an insult but now seems to have its own robust statistical future.

Bayesian and frequentist ideas are combined happily in the Fdr algorithm. Other lines are blurred too: in (2) we are *estimating* the *hypothesis testing* quantity (3); that is, we are carrying out an "empirical Bayes" analysis, to use Robbins' apt description. Blurred lines are another likely (and hopeful) trend, as Twenty-First Century statisticians outgrow the confines of classical theory.

In moving beyond the classical confines we are also moving outside its wall of protection. Fisher, Neyman et al. fashioned, with enormous intellectual effort, an almost perfect inferential machine for small-scale estimation and testing problems. It took our brilliant predecessors at least 25 years to work the kinks out of ANOVA/linear model theory. My guess is for another long period of progress and retrenchment. Difficulties with large-scale inference are easy to find. Not all microarray data sets are as obliging as that from the prostate study. Often the histogram is much wider or narrower than in Fig. 1, casting grave doubt on the adequacy of the textbook null hypothesis (1). Correlations sprawl across the z-values, undermining accuracy of the empirical Bayes estimator. Effect sizes for the genes deemed "non-null" are difficult to assess because of massive selection biases from choosing among so many candidates. Et cetera, et cetera. In other words, there is a lot for statisticians to think about over the next 25 years.

Some of that thinking will involve the legitimate use of Bayesian methods in large-scale inference. As an example, Fig. 2 concerns effect size estimation in the prostate study. Suppose that the z-value for gene i follows a normal distribution,

$$z_i \sim \mathcal{N}(\mu_i, 1), \tag{4}$$

μ_i the "effect size" (so $\mu_i = 0$ for the null genes (1)), where the effect sizes are drawn from some unknown Bayesian prior distribution $G(\mu)$. Call $f(z)$ the marginal density of z-values induced by $G(\mu)$ and (4). Then it is not difficult to show that expected effect size $\mu(z)$ is a simple function of $f(z)$,

$$\mu(z) = z + \frac{d}{dz} \log f(z). \tag{5}$$

The heavy curve in Fig. 2 is an empirical Bayes estimate of (5): a smooth curve $\hat{f}(z)$ was fit to the heights of the histogram bars in Fig. 1 and its logarithm differentiated to give $\hat{\mu}(z)$; see Efron (2009). Gene 610 has $z_{610} = 5.29$, the largest of the 6033 z-values, with effect size estimate $\hat{\mu}_{610} = 4.11$, as indicated.

We can be almost certain that z_{610}, as the maximum of $N = 6,033$ observations, exaggerates μ_{610}. This is the curse of selection bias. Bayes estimates, according to theory, are immune to selection bias: if $\hat{\mu}_{610}$ were a genuine Bayes posterior estimate of μ_{610}, we would not have to concern ourselves that gene 610 was selected on the basis of the data. A Bayes prior effectively postulates an *infinite* amount of relevant past experience, swamping selection effects from mere thousands of observations.

Are empirical Bayes estimates immune to selection bias? $N = 6,033$ is not $N =$ infinity, and we might suspect at least some selection effects to linger in $\hat{\mu}_{610}$. Other very appealing Bayesian properties, like the right to take interim looks at a clinical trial without an optional stopping penalty, are not put to the test in small-scale situations. Large-scale studies offer their own self-contained universes in which it may be possible to settle such questions.

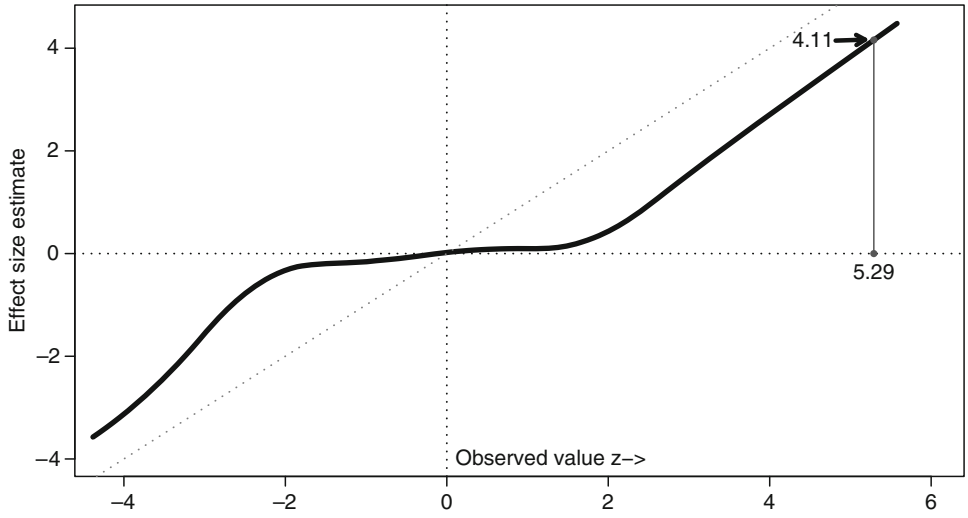

Figure 2 Effect size estimates for prostate study

Statistics is a second-level science: our "nature" is the data-analytic questions posed by front-line scientists – biologists, astronomers, economists, etc. – the "etc." by now spanning almost all areas of quantitative inquiry. The future of statistics depends on the future of science, in particular of scientific technology. There's a good chance that today's huge data sets will seem puny in a few years, in which case this little essay will look remarkably timid.

The future I've been discussing is that of statistics as an intellectual discipline. What about the future of the statistics profession? There is no question that the probabilistic/statistical point of view continues its relentless spread across science and engineering. (Maybe scientists are just running out of problems simple enough to solve deterministically.) So there will be more people interested in statistical questions, but that doesn't necessarily imply more statisticians. The field could fractionate into subject area subspecialties.

I don't think so. The health of a scientific profession can be rated on three criteria:

- An outside demand for answers in the profession's chosen area.
- Some evidence of past success in answering such questions.
- An ongoing production of useful new ideas.

In other words, the profession should be healthy from both an inside and outside point of view. I give statistics high grades on all three criteria, perhaps higher than at any time in the past half-century. In one sense we have a monopoly: statistics is the only profession that takes applied inference seriously as a subject of study. So in my view, our future work is cut out for us, but it's not cut out for anyone else.

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[Past President, American Statistical Association (2004), Past President, Institute of Mathematical Statistics (1987–1988), Founding Editor, The Annals of Applied Statistics (2006–), Bradley Efron, is considered as "one of the most innovative and original contributors to statistical science today" (StatNews, Penn State, December 2003). He is the Max H. Stein Professor of Statistics and Biostatistics at Stanford University's School of Humanities and Sciences and the Department of Health Research and Policy with the School of Medicine, USA. Professor Efron is member of American Academy of Arts and Sciences (1983) and National Academy of Sciences (1985). He has been awarded the Ford Prize, Mathematical Association of America (1978), MacArthur award (1983), Wilks Medal, American Statistical Association (August 1990), Fisher Prize, Committee of Presidents of Statistical Societies (July 1996), Parzen Prize for Statistical Innovation, Texas A&M University (1998), the first-ever C.R. & Bhargavi Rao Prize (2003), Noether Prize, American Statistical Association (2006). On May 29, 2007, he was awarded the National Medal of Science, the highest scientific honor by the United States "for his contributions to theoretical and applied statistics, especially the bootstrap sampling technique; for his extraordinary geometric insight into nonlinear statistical problems; and for applications in medicine, physics, and astronomy."

"Brad Efron is renowned as a quintessential, theoretical, mathematical, interdisciplinary, and applied statistician. His foreseeing the onset of cheap and fast computation inspired his most famous breakthrough in 1979, the 'bootstrap', which marks the onset of the computer intensive age in statistics." (Professor Carl Morris, Harvard University, Notices of the AMS, 2007, p. 999).]

Foreword by Rajko Kuzmanović

▸ *Inventas vitam iuvat excoluisse per artes*
Vergil

In the Republic of Srpska, and in Bosnia and Herzegovina, we need to encourage statistics both as a science and as an aid to developing the economy of our region. This *Encyclopedia* goes a significant way towards meeting that challenge. It provides us with international visibility in statistics, it demonstrates our unity, energy and judgement, and it shows our capacity for collaboration.

However, the *Encyclopedia* does much more than that. This storehouse of the knowledge and wisdom of statisticians from around the world displays the unity of the broad international statistics community, and provides a resource of substantial scientific benefit to all nations. It demystifies the concepts and philosophy of statistics, not just to students and researchers in the field but to their many non-statistician colleagues in other areas, who need to understand statistics in order to make progress in their own disciplines. As the historian Theodore Porter wrote, "statistics . . . is evidently among the products of science whose influence on public and private life has been most pervasive."

For all these reasons we believe that the *Encyclopedia* will become the starting point for still further development of scientific knowledge, and be of influence for many years to come. At least in our region we feel that time, in the statistics community, will henceforth be designated as BE or AE — before the *Encyclopedia*, or after it.

Speaking personally, it is with unconcealed pride in this achievement that I take this opportunity to express my great satisfaction with the project, and my deep gratitude to the scientists and scholars who have contributed so generously to it. I believe that the *Encyclopedia* will inspire a younger generation of statistical scientists to study and dedicate themselves to the discipline. It will draw them closer to researchers in many other fields, and closer too to their colleagues in other nations.

President
Academy of Sciences and Arts
Republic of Srpska

Academician Rajko Kuzmanović, Ph.D.

Preface

- *Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write.*
  Samuel Wilks (paraphrasing Herbert G. Wells)
- *The quiet statisticians have changed our world—not by discovering new facts or technical developments, but by changing the ways we reason, experiment and form our opinions about it.*
  Ian Hacking, Contemporary Philosopher

Why is there a need for one more encyclopedia and *what is so special and unique* with the book that you have just started reading? After perusing the prefaces to at least 300 encyclopedias, I can provide 10 distinctive arguments and answers:

1. As you will see more in the next section the main objective of this project, **help reviving statistics education in developing countries**, is very different and broader and has a valuable social dimension. This goal has attracted and united many leading world statisticians, four Nobel Laureates, many eminent mathematicians, psychologists, philosophers, econometricians, economists, academicians, Presidents and founders of Statistical societies, and Editors and Associate Editors of many reputed international journals, who have decided to participate.
2. One of the hallmarks of the Encyclopedia is its international scope, it has **619 contributors from 105 countries** making this assignment one of the largest international scientific projects ever undertaken (from the perspective of the number of countries involved), not only in Statistics, but also in other branches of Science. We have shown that statistical science does not recognize and cares for country borders and customs; this united world effort encompasses countries that overall include more than 90% of the world population altogether, in a way we have fulfilled John Lennon's dream: "and the world will be as one".
3. Many of our papers have resulted as collaborations of authors coming from different countries, for example we have a paper written by authors from USA and Russia, paper by authors from USA, Philippines and Spain; from Serbia and Croatia; Australia, UK and Switzerland, to mention a few.
4. For the first time authors from many developing countries have had an opportunity to work together on the same project with the leading world authorities in statistics and quantitative methods.
5. Almost all leading experts from many developing countries have been involved, including presidents of their statistical societies. This encyclopedia has contributors from almost all countries in the world that have statistics departments or professors in statistics;
6. Many papers from this encyclopedia have been selected to provide the backbone of **StatProb**, the **free** online encyclopedia of statistics, sponsored by statistics and probability societies (http://statprob.com).
7. This project has several contributors whose papers can be regarded as conveying an encouraging and mesmerizing message "never say never" to all of us, for example one author has been blind since 1993 and yet provided a paper with many formulas, several most distinguished authors are over 90 and one is even 101 years old.
8. In contrast to almost all other encyclopedias, this one includes achievement biographies of many contributed authors.
9. To overcome pervasive stereotyped public images that Statistics is dull and boring, I invited many authors to write non-standard papers with our joint vision: to show not only that Statistics is a "grammar of science", but also a fascinating, attractive, stimulating, beautiful, almost magical discipline with plenty of room for fundamental improvements. For example, instead of standard foreword, Professor Bradley Efron has given his vision on the future of statistics. Former President of the American Statistical Association, Jon R. Kettenring, has written the paper on "The Rise of Statistics in the Twenty First Century" mentioning the headline that appeared on the front page of The New York Times: "**For today's graduate, just one word: statistics**." Professor Shlomo Sawilowsky has written a paper "Statistical Fallacies, Misconceptions, and Myths", Professor Jan Kmenta "Econometrics: a failed science?", Professor Jagdish

Srivastava "Clinical Trials: Some Aspects Of Public Interest", Professor William Notz "Statistics - Resolving Controversies In Practice", Professors Bruno Lecoutre and Shlomo Sawilowsky contrast their views on hypothesis testing, and Professors John Nelder and Herman Rubin give their different views on statistics, etc.

10. This encyclopedia includes last papers and words written by four eminent statisticians who had made great contribution to our science.

The Origin of the Encyclopedia and Its Goal

This project started to correct the lacuna in Statistics education in Macedonia, Serbia, Montenegro and Bosnia that were once part of former Yugoslavia. After long discussions, an Organizational Committee was formed for writing and promoting a **Dictionary of Statistics** and as many such dictionaries were on the market, the title was changed to **Lexicon of Statistics**.

The Organizational Committee was structured such that from each of the former Yugoslavian republics (except Monte Negro) a president was elected (in alphabetical order):

Bosnia: Professor *Jasmin Komić* (also the President of the Committee),
Croatia: Professor *Ksenija Dumičić*,
Macedonia: Professor *Kalina Trenevska Blagoeva*,
Serbia: Professor *Milan Merkle* and
Slovenia: Professor *Jože Rovan*.

Initially, the idea was to invite only the statisticians from the former Yugoslavian republics. It had been regarded as a significant success to realize a project with authors coming from all these republics, for the first time after the "third Balkan war". The choice of the language was very difficult because of the different dialects (languages), and finally we decided to select English as the official Lexicon language. Later, some of the eminent statisticians and professors (in chronological order) *Peter Hall*, *Bradley Efron*, *James Hamilton*, *Robert Tibshirani*, *David Moore*, *Ronald Iman*, *Peter Diggle* and *E.L. Lehmann* have submitted brief definitions of some statistical terms. However, a few like *Thomas Hettmansperger*, *Peter Kennedy*, *Geert Molenberghs*, *Hirotogu Akaike* and *Alan Agresti* submitted brief articles. This reshaped my vision to strive for brief articles rather than definitions. Sir *David Cox* who pointed to some important statisticians in Europe provided the major impetus for this idea.

In preparing for this expanded project the committee realized that Statistics education is also on the decline in many developing countries. After I exchanged more than 5000 emails with statisticians from all over the world, the scope of the project was further broadened to **revive interest in Statistics in developing countries**. The response was so unprecedented and unbelievable that the title of this project was changed from Lexicon of Statistics into International **Encyclopedia** of Statistical Science.

I have decided to include the Lexicon part and the interested reader can find it in the volume 3.

All the contributors have committed themselves to giving our readers the best, despite the imperfections that inhere in any human endeavor. We hope that those who use this encyclopedia experience the pleasure and insight that we have worked to provide.

If this united world effort ignite a spark of enthusiasm about statistics and henceforth revitalize interest in statistics education in developing countries and also inspire many high school students to study statistics we will consider mission fulfilled.

Finally, I should mention that during this process, four of our esteemed contributors have passed away, Professor **Hirotugu Akaike**, Nobel Laureate Sir **Clive Granger**, Professor **Erich Lehmann** and Professor **John Nelder**. Each of these figures have made considerable contributions to our discipline, and will be sadly missed. I feel it appropriate to **dedicate the Encyclopedia to their memory**.

List of Articles by the Reader's Background

This encyclopedia has 636 entries arranged in alphabetical order. There are many co-authored papers and at the same time many authors have written two or more papers, Professor Sander Greenland even nine. The Encyclopedia includes extensive cross-referencing of two types: inline (included within a body of a paper) and "external" (provided at the end of the entry). Responsibility for these cross-references lies ultimately with me, though I am thankful to those authors who

have suggested cross-references for their own papers. This work was designed to provide useful **up-to-date trustworthy** information, including the **latest advances** in statistics, for different categories of users:

High school students (they are strongly advised to read the papers "Statistics: An Overview", "Careers in Statistics", "Rise of Statistics in the Twenty First Century", "Statistics: Nelder's view" and the "Role of Statistics", among others).

Undergraduate students in almost any field (they can start reading this encyclopedia by finding the paper on the relation of statistics and their particular field of study).

Businesspersons (they can find valuable information in the following entries, among others,: "Business Forecasting Methods", "Forecasting Principles", "Business Statistics", "Economic Statistics", "Detection of Turning Points in Business Cycles", "Business Intelligence", "Data Mining" and "Business Surveys").

Researchers in all branches of science (they are urged to start reading the following entries: "Research Designs", "Statistical Significance", "Statistical Evidence", "Null-Hypothesis Significance Testing: Misconceptions", "Effect Size", "P-Values", "Bayesian Versus Frequentist Statistical Reasoning", "Statistical Fallacies: Misconceptions, and Myths", "Significance Tests: A Critique" and "Frequentist Hypothesis Testing: A Defense").

Authors of the introductory university statistics textbooks (they could start by reading the following entries: "Statistics: An Overview", "Statistical Literacy, Reasoning, and Thinking", "Statistical Inference: An Overview", "Bayesian Versus Frequentist Statistical Reasoning," "Bayesian Statistics", "Psychology, Statistics in", "Misuse of Statistics", "Statistical Fallacies: Misconceptions, and Myths", "Statistics: Controversies in Practice", "Null-Hypothesis Significance Testing: Misconceptions", "Effect Size", "Role of Statistics", "Statistics Education", "Data Mining", "Online Statistics Education", "Measurement Scales And Choice Of Statistical Method", "Harmonic Mean", "Sturges' and Scott's Rules", "Skewness", and "Significance Testing: An Overview". They will certainly find a wealth of information and many issues that they could cover or amend in their future editions, and many new angles on all those topics, that they could not find in standard textbooks).

All other readers can start using the encyclopedia by reading the entries "Statistics: An Overview", "Clinical Trials: Some Aspects of Public Interest", or "Rise of Statistics in the Twenty First Century". We believe that any non-statistician will be able to obtain quick and yet comprehensive and highly understandable view on certain statistical terms, methods or applications. Additionally, we trust that all researchers, managers and practitioners will regard this encyclopedia as a highly valuable resource that will help them refreshing their knowledge in Statistics, especially in certain controversial fields.

Acknowledgments

I would like to express my profound thanks to all our contributors who have made substantial and Herculean efforts and devoted their valuable time to support this project. This is neither a Serbian nor a Yugoslavian Encyclopedia, but a **joint work** of many leading statisticians, economists, philosophers, engineers, sociologists, econometricians, psychologists and other scientists from all over the world, and is truly a **World Encyclopedia**. Throughout the progress of this work almost all authors have given many invaluable ideas to improve some entries and to include other topics, or suggestions to invite other eminent scholar.

The **Ministry of Science of the Republic of Srpska**, **Rajko Kuzmanović**, **President (2007–2010)**, **Milorad Dodik, Prime Minister (2006–2010**, **now President)** and the **University of Banja Luka** accorded formal recognition to this project and helped me substantially to complete it.

I would also like to especially thank Presidents and Past Presidents of many statistical associations for their support and contributed papers, including the ones from the following countries (alphabetically): Argentina, Armenia, Austria, Belarus, Belgium, Brazil, Canada, Chile, China, Estonia, Germany, Hong Kong, India, Ireland, Israel, Italy, Japan, Korea, Kyrgyzstan, Mexico, Nepal, New Zealand, Palestine, Saudi Arabia, Slovenia, South Africa, Sweden, The Netherlands, Turkey, Uganda, UK, and USA;

I am indebted to Presidents, Past Presidents, Directors and Chairmen of many reputed international scientific organizations for their decisions to take part in this project, including: *Academy of Marketing Science*, *African Centre for Statistics*, *Bachelier Finance Society*, *Bernoulli Society*, *European Consortium for Mathematics in Industry*, *European Consortium of Sociological Research*, *European Society for Mathematical and Theoretical Biology*, *Eurostat*, *Institute of Mathematical Statistics*, *International Association for Statistics Education*, *International Association of Survey Statisticians*, *International Biometric Society*, *International Chinese Statistical Association*, *International Federation of Classification Societies*, *International Federation of Nonlinear Analysts*, *International Indian Statistical Association*, *International Society for Bayesian*

Analysis, *International Society for the Study of Work and Organizational Values*, *International Society on Multiple Criteria Decision Making*, *International Sociological Association*, *International Statistical Institute*, *Islamic Countries Society of Statistical Sciences*, *Omega Rho*, *Psychometric Society*, *Scandinavian Demographic Society*, *Sensometrics Society*, *Society for Applied Multivariate Research*, *Society for Marketing Advances*, *Statistical Modelling Society*, and *United Nations Statistical Commission*;

The major help throughout the realization of this project I received is from the following Organizational Committee members: Professor **Jasmin Komić**, Professor **Ksenija Dumičić** and Professor **Milan Merkle**. It is fair to say that the whole idea of Lexicon came out in my long stimulating discussions with Dr. Komić, after we published our joint statistics textbook for the university students in Republic of Srpska. Also, I would like to mention my close friend, Professor *Vladislav Milošević* who was not fortunate enough to see this book as he passed away in 2009. He was always there to encourage me and to share the ideas.

I am extremely grateful to all of our reviewers whose constructive comments greatly improved many entries. In this project *peer-to-peer reviewing process* was applied, and many of our contributors took a dual role and reviewed papers from their field of expertise. Their valuable help is here acknowledged with gratitude. In the reviewing process, however, many papers had to be rejected, since the highest possible standard was applied. Additionally, I am sorry to say that for many papers I could not find the scholars that had time and willingness to provide me a report on these papers. As a result we have about 50 papers still waiting for the referees, and hopefully some will be published in the next edition.

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It would be highly inappropriate to single out any of the contributed authors. I would only like to mention that the first paper was written by Professor Peter Hall and the last one by Professor C.R Rao.

There were many ups and downs, and also many critical moments during the realization of this huge project. I succeeded (better to say survived) owing to two factors.

1) I was very fortunate to have had never-ending support of my wife and family.

2) Whenever there was a crisis or some extremely difficult phase (like for example building cross-references, there are about 4500 "external" and few thousand inline ones), I received an unprecedented support and encouragements from our authors that gave me the additional energy and strength to carry on.

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Pro Statistica Scientia, Pace et Fraternitate Gentium

About the Editor

Dr. Miodrag Lovric is Professor of Statistics, Department of Statistics and Informatics, Faculty of Economics, University of Kragujevac, City of Kragujevac, Serbia. He obtained his Ph.D. in Statistics at the University of Belgrade in 1986, where he worked on the efficiency and robustness of nonparametric rank tests (especially on the relevance of the Pitman asymptotic relative efficiency in the case of moderate sample size). He was teaching and performing research in Belgrade. During the war in Yugoslavia, he decided to leave Serbia and move to New Zealand. He joined the Open Polytechnic of New Zealand in 1995 and was involved in distance education. In 1996 he joined Wellington Polytechnic (now part of the Massey University), where he delivered a range of courses starting from programming languages, data analysis, and quality assurance to applied statistics. In 1999, he moved to Australia to join the School of Mathematics and Statistics at the University of South Australia, Adelaide. He was responsible for teaching statistics to a broad spectrum of students in the fields of business, engineering, pharmacy, biology, chemistry, and science. During this period he received from many students very negative comments about the usefulness of statistics and realized that something radically new has to be done to convey the relevance, beauty, and the universal value of statistical thinking and reasoning to them. He thought that some new educational, user-friendly, statistical software that would guide users and help choose the optimal method and provide interpretations of the results could create a friendlier attitude toward statistics. Therefore, he spent several years designing and developing such statistical software (titled EduStat).

In 2002, he moved back to Serbia and was appointed as a Professor of Statistics at the University of Belgrade and at the University of Kragujevac since 2008. Although his statistical software is currently in use at more than 30 faculties in this region and presented in many TV channels in Serbia, Dr. Lovric was unable to make any significant impact and attract new students for statistics in Serbia. Soon he realized that statistics education is in deep crisis in almost all of the former Yugoslavian republics, and from 2005 has completely devoted himself to a new project that finally resulted in this Encyclopedia.

Dr. Lovric has (co)authored many papers and several statistics textbooks (mainly in Serbian) that are widely used in this region. Recently, he had delivered lectures for undergraduate, graduate, postgraduate, and Ph.D. students in Economics, Pharmaceutical Medicine, and Veterinary Science in Serbia and Bosnia. He was a leader of many projects, including the ones for the Belgrade Stock Exchange, Ministry of Trade and Tourism, Ministry of Finance, and Ministry of Internal Affairs, Serbia. He has designed and developed several software products for the company Insight Data in Auckland, New Zealand, and an election software for one of the leading parties in New Zealand. He is a member of the

Editorial board of the *Statistics Review*, the only statistics journal in this region. Recently, he has been elected as a member of the panel of examiners for Ph.D. students in several countries. In 2009, he was elected as President of the International Federation of Nonlinear Analysts (Serbian Branch). His research interests are very broad, including philosophy and foundations of statistical science, statistics education, history of statistics and statistical software. He has also a keen interest in the evolution, creationism, and intelligent design controversy, special and general theory of relativity (including their criticism), theory of parallel universes, and cosmology. However, with the realization that in more than 100 countries in the world there is not a single professor in statistics, his main focus became a quest to find ways to revive statistics education in this region as well as in many developing countries. Professor Lovric is a Fellow of the Royal Statistical Society.

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