

C. R. Rao is 100

The living legend and doyen of Indian Statistics celebrated his 100th birthday on September 10, 2020. On the preceding day, there was an online celebration, organized by the Indian Statistical Institute, and talks were provided by Indian and American mathematicians. Prof. Rao himself was present, he is still an active researcher, currently in the US.

Short biography of C. R. Rao

C. R. Rao was born in 1920 in Huvanna Hadagali, now in Karnataka State, in the southern part of India. He was the eighth child in a family of six brothers and four sisters and was named Radhakrishna following the tradition of naming the eighth child after God Krishna. His father was a police inspector and the family moved frequently; however, he benefited a lot from her mother's discipline and his father's encouraging him to solve mathematical problems. At his age of five, he was able to multiply together numbers up to 16×16 , so he started school then, and went to the Andhra University when he was 17. There he obtained his B.A., then M.A. degree in mathematics, when he was 20. He wanted to have a research scholarship and PhD degree, but it went not so smoothly as he had thought it. First he was not accepted. Then he read in a newspaper, that engineering training for jobs are open in the military.

About the turning point of his life we cite A. K. Bera (University of Illinois, Urbana-Champaign): ET Interview with C. R. Rao (in *Econometric Theory* 19, pages 329-398, 2003).

"It was June 1940. The Second World War already raging in full swing in its devastation. A young man not yet 20 set out on a 500-mile train journey to Calcutta, the second largest city of the British Empire, after obtaining a first-class degree in mathematics and with a glimmer of hope of finding a job in the military. The young man was not so lucky; he was deemed too young for the job. However, while in Calcutta, he visited the Indian Statistical Institute (ISI) founded in 1931 by Prof. P. C. Mahalanobis, a Cambridge-trained physicist. As a last resort he applied for a one-year training program in statistics there. Very promptly he received a positive reply from Prof. Mahalanobis."

In this way, the young man stayed for 40 years in Calcutta (now Kolkata). After getting his M. A. degree in statistics from the Calcutta University, he worked there as a research scholar, superintending statistician, professor and head of Research and Training School, later (after the death of Mahalanobis) director of the ISI, Jawaharlal Nehru Professor and National Professor, before he took mandatory retirement at the age of 60. Then he started a new career in the USA.

In 1946 he was invited to work in a project at the Museum of Anthropology and Archeology at Cambridge University, UK, which required the methodology developed by P. C. Mahalanobis. Based on this work and for developing the multivariate analysis of variance (MANOVA), he earned his Ph.D. in 1948 from Cambridge University under the supervision of Sir R. A. Fisher, founder

of modern statistics. (In fact, he was the only Ph.D. student of this strange professor.) A few years later, in 1965, the Cambridge University awarded him the prestigious higher doctorate Sc.D. degree based on a peer review of his research contributions to statistics.

Between 1953–1979 he spent some years in the United States (University of Illinois, John Hopkins University, Indiana University, Ohio State University, and Stanford University) as a visiting professor. After his retirement from the ISI, he moved to the USA and worked for another 25 years as a university professor first at the University of Pittsburgh, then at the Pennsylvania State University, where he is now an Eberly Professor of Statistics. He retired from teaching at the age of 80, but he was still active as the Director of the Center for Multivariate Analysis at Pennsylvania State University, now he is in Buffalo. He usually spends the April–October period in the USA, and the other half year in India, where he founded the C. R. Rao Advanced Institute of Mathematics, Statistics and Computer Science (CRRAO AIMSCS), at the University of Hyderabad Campus

Academic qualifications and selected awards C. R. Rao received

- M.A. degree in mathematics at the Andhra University in Waltair, Andhra Pradesh (1941), with first class and first rank.
- M. A. degree in statistics from Calcutta University, West Bengal (1943), with first class, first rank, and record marks unbeaten till now; further with a gold medal.
- Ph.D. at Cambridge University, UK (1948).
- Sc.D. by peer review of published work, Cambridge University, UK (1965).
- He received 33 honorary doctoral degrees from universities of 18 countries spanning 6 continents.
- Some examples of his numerous Indian and international awards:
 - Shanti Swarup Bhatnagar Award of the Indian Council of Scientific and Industrial Research, from Prime Minister Nehru in 1963. C. R. Rao donated the entire prize money to the National Defense Fund saying that “The country’s need is greater than that of an individual scientist”.
 - National Medal of Science, USA in 2002, from the American president, G. W. Bush, calling him “a prophet of new age”.
 - India Science Award “for his significant contributions to the field of statistical science during an illustrious career spanning six decades”, given by the Prime Minister of India in 2009.
 - Radhakrishna (C. R.) Rao was awarded the Guy Medal in Gold of the Royal Statistical Society, UK on the 29th of June, 2011 “For his fundamental contributions to statistical theory and methodology,

including unbiased estimation, variance reduction by sufficiency, efficiency of estimation, information geometry, as well as the application of matrix theory in linear statistical inference”, the announcement stated. The Gold Medal is awarded by the Royal Statistical Society (triennially, except the war period) and named after William Guy. There are Silver and Bronze Medals too, C. R. Rao already obtained the Silver Medal in 1965. Since 1892 he is the 34th recipient of the Gold Medal. Previously, R. A. Fisher (1946), E. S. Pearson (1955), J. Neyman (1966), M. S. Bartlett (1969), H. Cramér (1972), and D. Cox(1973) received this prize, just to mention a few. Among the recipients only H. Cramér and J. Neyman were outside Great Britain. C. R. Rao is the first non-European and non-American to receive the award.

Development of statistics in India, his school and students

C. R. Rao organized research and training programs for outstanding students which “put India not far from the center of the statistical map of the world”. He was the chairman of the UN Committee, which examined the demand for statistical personnel in Asian countries and recommended the establishment of an Institute for statistical development in South East Asia. On the basis of this recommendation the Asian Statistical Institute now known as Statistical Institute for Asia and Pacific was established in Tokyo to provide training for statisticians working in government and industrial organizations. Already P. C. Mahalanobis started setting up state statistical bureaus in different states of India and developing a network of statistical agencies at the district level for collection of data. Together with the Central Statistical Organization and the National Sample Survey in Planning of which C. R. Rao played a significant role, India has one of the best statistical systems. He founded the Indian Econometric Society, which has been active in promoting quantitative studies in econometrics for planning purposes. He also founded the Indian Society for Medical Statistics which holds conferences every year to discuss problems of current interest.

His international positions: he was the president of all prestigious statistical associations, the International Statistical Institute, Institute of Mathematical Statistics, USA and the International Biometric Society.

Above promoting the applications, he supervised the doctoral research of 50 students who have, in turn, trained another 390 doctoral students themselves. Most of his former students now are employed in universities and other research organizations worldwide, many becoming research leaders in their areas of specialization. For example, D. Basu (his first PhD student with important contributions to the theory of sufficient and complete statistics), S. R. S. Varadhan (Abel prize winner), U. S. R. Murthy, and S. B. Rao were his Ph.D. students. In reply to a query put to him as what particular achievement he is most proud of, C. R. Rao replied: “it is the outstanding contributions my students are making to statistical theory and practice”.

Publications

He is the author of 16 books and about 350 research papers in high impact journals. Three of his books have been translated into several European, Chinese, and Japanese languages. His most cited books are the following:

- **Linear Statistical Inference and its Applications**, John Wiley, first edition: 1965, second edition: 1973.

Amazon.com lists this book under the list of “Must-have statistics books”, quoting a reviewer’s comment “information packed book, bible of matrix and linear theory in stat”.

- **Statistics and Truth**, World Scientific, first edition: 1989, second edition: 1997. Review by statistician Sir David Cox: “The book is a powerful illustration of the nature of statistical arguments and I can think of no better book to introduce the subject, in particular to a general reader.”

His more recent publications related to modern statistical methods:

- G.J. Babu, C.R. Rao, Bootstrap methodology. Handbook of Statistics, Vol 9, pp. 627-659, Elsevier (1993).
- B. B Pereira, C.R. Rao, F.B. Oliveira, Statistical Learning and Neural Networks. A Guide for Statisticians and Data Scientists with Python. Handbook of Statistics, CRC Press, Taylor and Francis Group (2020).
- A.S. Rao, C.R. Rao eds.: Principles and Methods for Data Science. Handbook of Statistics 43, North Holland, Elsevier (2020).

Breakthroughs in statistics

C. R. Rao is among the world leaders in statistical science over the last seven decades. His research, scholarship, and professional services have had a profound influence on theory and applications of statistics. His research in multivariate analysis, for example, is useful in economic planning, weather prediction, medical diagnosis, tracking the movements of spy planes, and monitoring the movements of spacecrafts. Technical terms bearing his name appear in all standard textbooks on statistics, econometrics, biometrics, and engineering. Examples of these terms are the Cramér–Rao Inequality, Rao–Blackwellization, Fisher–Rao Theorem, Rao Distance, Rao’s Orthogonal Arrays, Multivariate Analysis of Variance, Canonical Variate Analysis, and Generalized Inverse of matrices.

He invented his famous inequality in one night of 1944, when a student asked him about the existence of a strict inequality for the lowest possible variance attainable by an unbiased estimator (asymptotic results were already known). In fact, in the proof he carried out an accurate error calculation that already foreshadowed his powerful information and differential geometry techniques. Remarkably, this calculation – under certain regularity conditions – leads to a formula using the already existing Fisher-information. The inequality was discovered independently by the Scandinavian statistician H. Cramér in 1945.

C. R. Rao published this result in his seminal paper together with the Rao–Blackwellization also invented by D. Blackwell and based on the notion of conditional expectation introduced by A. N. Kolmogorov. The details of this first full-length paper of C. R. Rao are the following:

C. R. Rao: Information and Accuracy Attainable in the Estimation of Statistical Parameters, *Bulletin of Calcutta Mathematical Society* 37, pages 81-91 (1945). This paper has been reprinted in the book **Breakthroughs in Statistics 1890-1990**, Springer-Verlag, together with an other paper published when he was 28 years old, which gave rise to the technical term Rao’s Score Test.

These very concise papers of his twenties opened new areas of research and generated a number of further technical terms appearing in specialized literature, like Quantum Cramér–Rao Bound providing sharper versions of Heisenberg’s Principle in Quantum Physics. His impact on Multivariate Statistical Analysis is exemplary. He elaborated a unique basis of the already known and newly introduced methods by means of the spectral and singular value decomposition of matrices. He defined a Generalized Inverse (g-inverse) of a matrix (singular or rectangular) and demonstrated its usefulness in the study of linear models and singular multivariate distributions. He also made significant contributions to combinatorial mathematics for use in design of experiments, the most important of which is Orthogonal Arrays. In the last decades he also touched upon non-linear methods, resampling methods (he wrote a handbook on Bootstrap), neural networks, and data mining.

C. R. Rao as a person

He has a great sense of humor and deep interest in everything related to data analysis and statistical education. When I first met him at the Penn State University, he was interested in Hungarian mathematics and statistics; he knew Alfréd Rényi (who was born half a year later than Rao, but lived unfortunately less than 50 years). When I visited his institute in Hyderabad (2010-2011), I had the opportunity to meet his wife, Bhagravi who has two master’s degrees, one from Banaras Hindu University in History and another from the University of Illinois, USA, in Psychology. She used multivariate statistics to analyze psychological data by reducing the dimensionality. She worked as a professor of psychology at Jadavpur University, Kolkata for a number of years,

They have a daughter, Tejaswini who holds a Ph.D. in Nutrition from the Pennsylvania State University and works as a Professor in the Dietetics and Nutrition Department of the SUNY College, Buffalo. She is also an accomplished dancer of Indian classical dances and the director of a dance school called Natya. Their son, Veerendra is an electrical engineer and computer scientist. He has a computer consultancy business in Pittsburgh. He has two sons.

As I got known from Prof. S. B. Rao, Director of the CRRAO AIMSCS, C. R. Rao has a strict daily routine. He gets up early in the morning and works at candle light, making hand calculations on a paper. He also uses e-mail and internet, types his papers and books. After the millennium, he was active in developing a research institute to promote research in mathematics, statistics, and computer science. With the help of funds raised by him, including his own substantial contribution, and a grant from the Prime Minister, a building named as CRRAO AIMSCS has been built on the campus of the University of

Hyderabad (in Andhra Pradesh, not far from the place he started his university studies). Nearby the campus area the main road is named “Prof. C. R. Rao Road”. He and his wife have made other funds too. He also established of a museum of statistics, the C. R. Rao Gallery, registered as “Sankhya: The National Museum of Statistics” in Hyderabad, as the first one of this kind over the world and much needed venue for encouraging young students to study statistics.

Appendices (in separate files)

- Pictures with his famous co-authors.
- Soon, I will upload a lecture note about his fundamental findings: minimum variance unbiased estimators, Cramér–Rao inequality, Rao–Blackwellization. I will introduce notions, like sufficient statistics, maximum likelihood method that are necessary to understand these results. Actually, I teach this stuff in two semesters for Hungarian students and believe that can be understood on BSc level.
- Pictures of him when admits some of his famous awards. Actually, in 1963, he accepted the award from prime minister Nehru, but gave the money to India.

This report was written based on existing biographies, publications of the CRRAO AIMSCS, and personal conversations with Prof. C. R. Rao.

Budapest, 17 October, 2020.

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Prof. DSc.