An interview with Professor C.R. Rao on the occasion of his 100th birthday

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Abstract

The late Professor C.R. Rao's contributions have shaped the theory, application and future of statistics and statistical theory. It is these contributions that have made him a highly respected figure in the academic community. In this email interview, Professor Rao shares valuable insights into statistics and reflects on his passion, expertise and remarkable career in the field.

Introduction

Calyampudi Radhakrishna Rao, known as C.R. Rao, was born on September 10, 1920, in Huvvinna Hadagalli, a small town in South India. Born as the eight child among the ten children of C.D. Naidu and Laxmikanthamma, Rao grew up to become one of the world's most significant statisticians. Further details about Professor Rao's life and career are available in the published interview [1].

Professor C. R. Rao is the author of fifteen books, including Statistics and Truth, which has been translated into French, German, Japanese, Main Land, Taiwan Chinese, Turkish, and Korean. Another book, Linear Statistical Inference, has been in print as a textbook for more than fifty years and is available in Russian, German, Czech, Polish, Chinese, and Japanese. Professor Rao has also published more than 400 research papers in prestigious journals. He has edited 39 volumes of the Handbook of Statistics, which include existing statistical approaches and their real-world applications [2].

Technical terms found in all standard statistics books include Cramer-Rao inequality, Rao-Blackwellization, Rao's Score Test, Fisher-Rao and Rao Theorems on second order efficiency of an estimator, Rao metric and distance, Analysis of Dispersion (MANOVA), Canonical Variate analysis, and G-inverse of matrices. The two most often used keywords in statistical and engineering literature are Cramer-Rao Bound and Rao-Blackwellization. Within the field of Quantum Physics, Cramer-Rao Bound has found specific applications known as Quantum Cramer- Rao Bound. Particle filtering in high-dimensional state spaces, dynamic Bayesian networks, adaptive sampling, and other fields have found use for Rao-Blackwellization. The detection of signals, tracking of hostile aircraft, and shape-based object recognition have all benefited from these findings, which have strategic implications [3].

Rao's F– and U–tests in multivariate analysis, Rao's Quadratic Entropy, Cross Entropy, and Rao-Rubin, Lau-Rao, Lau-Rao-Shanbhag,
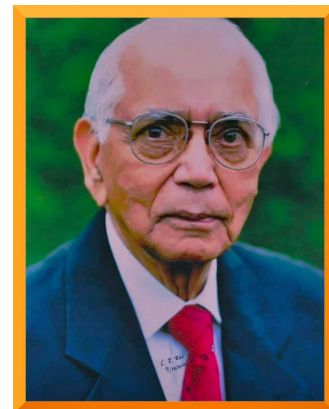
At a birthday celebration held at the home of his daughter, Dr. Teja Rao, in Buffalo, New York, on September 10, 2020, Dr. C.R. Rao signed and dated this photo. Hundreds of students and well-wishers watched it remotely on Zoom.

and Kagan-Linnik-Rao theorems on characterization of probability distributions are other technical words carrying his name that can be found in specialized literature. The book Breakthroughs in Statistics: 1889-1990 includes two of his papers: one on estimating that gave rise to numerous technical terms and essential concepts, and another on score tests that had a significant influence on the evolution of statistical theory. Orthogonal arrays (OA), one of Rao's most notable contributions to combinatorial mathematics for experiment design, are vital.This fundamental study first appeared in Proc. Edinburgh Math. Soc. (the publication's referee noted that it is a new and unique work). OAs, which Forbes Magazine called the "new mantra" for industries, were widely used in industrial experiments by the Japanese quality control expert G. Taguchi. In order to help with the study of linear models and singular multivariate normal distributions, Rao created a generalized inverse (g-inverse) of a matrix, which can be either singular or rectangular [3].

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Rao was selected earlier this year to receive the 2023 International Prize in Statistics, which is regarded as the Nobel Prize in statistics. Rao is a trailblazer in the area who established the groundwork for contemporary statistics. Rao's "work more than 75 years ago continues to exert a profound influence on science," the International Prize in Statistics Foundation said in announcing Rao's award. It also said that three fundamental results published in 1945 "paved the way for the modern field of statistics and provided statistical tools heavily used in science today" [4].

As stated in the release, the first result—referred to as the Cramer-Rao lower bound—offers a way to determine whether an estimation technique is as accurate as it gets. The method for converting an estimate into an ideal one is offered by the second result, known as the Rao-Blackwell Theorem. When combined, the two approaches provide the framework around which most statistics are constructed [4].

The realization of Rao's third result opened up a new field of study known as "information geometry," which has made significant contributions to the field of artificial intelligence and has been applied to recent research on radars and antennas, Higgs boson measurements at the Large Hadron Collider, and other fields [4].

When he was just twenty-five years old, Calyampudi Radhakrishna Rao made those three discoveries that laid the foundation for statistics as a discipline of study distinct from mathematics at the Indian Statistical Institute, where he worked for forty years [4].

In addition to the International Prize in Statistics this year, Rao's contributions have earned him the Padma Bhushan (1968) and the Padma Vibhushan (2001), the National Medal of Science (2002) in the US, the Shanti Swarup Bhatnagar Award (1963), and the India Science Award (2009) [4].

The Professor C. R. Rao Award in statistics is given out by the Indian government every two years. While in Hyderabad, he is honored with the namesake Prof C R Rao Road and the CR Rao Advanced Institute of Mathematics, Statistics, and Computer Science. The C R and Bhargavi Rao Prize in Statistics has been established by Pennsylvania State University [4].

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This interview was conducted via email by Kishor Khanal (KK) and Shankar Prashad Khanal (SPK) on the occasion of Rao's birth centennial. Professor Rao was sent a set of questions in early 2019, and he responded to them at different times between March 30, 2019 and March 10, 2022. Professor Rao passed away on August 22, 2023 at the age of 102 in Buffalo, New York.

KK & SPK: Professor Rao, Namaskar. We are pleased that you agreed for this interview, and we thank you for the opportunity. We hope this interview will be valuable for us all in the academia. As far as we know, this is your first interview with Nepali scholars, and we feel lucky. We studied some of your theorems and even taught them in university-level statistics courses, so we are eager to know more about you and your contemporary world. We hope Nepali scholars and students of statistics as well as all quantitative researchers will enjoy reading your interview and benefit from it. We also hope that this interview will be equally important for many scientists and scholars throughout the globe. Let us start this interview by asking you to explain in brief about your present activities.

Thank you for your questions.

Brief academic activities of Rao

Indian Statistical Institute, in various capacities	1941–1979
Visiting Professor at the University of Illinois	1951–1952
National Professor of India	1987–1992
University Professor, University of Pittsburgh	1979–1988
Eberly Professor of Statistics,	
The Pennsylvania State University (PSU), PA, USA	1988–2001
Eberly Professor Emeritus (PSU)	2001–
Director, Centre for Multivariate Analysis, PSU	2001–2010
Research Professor, University at Buffalo, SUNY	2010–

Retired from active service at the age of 80 from The Pennsylvania State University, PA, USA, and continues to hold honorary Professorship at The Pennsylvania State University, PA, USA, and at the University at Buffalo, SUNY, USA.

Most recent publications

Shi, Xiaoping & Wu, Yuehua & Rao, Calyampudi. (2018). Consistent and powerful non-Euclidean graph-based change-point test with applications to segmenting random interfered video data. Proceedings of the National Academy of Sciences. 115. 201804649. 10.1073/pnas.1804649115.

Jin, Baisou & Wu, Yuehua, Rao, Calyampudi Radhakrishna, & Hou, Li (2019). Estimation and model selection in the general spatial dynamic panel and data models.

Proceedings of the National Academy of Sciences. Vol. 300, No. 2, Dec. 18.

Another research article has been accepted for publication in the Proceedings of the National Academy of Sciences in 2020.

KK & SPK: In your long and in-depth interview [1], you explained important and interesting events about your childhood and school life. Besides those, will you please share with us some other memorable events of your childhood, school and college days?

Rao gives credit for his academic success to his mother who taught him diligence:

"... in my younger days, my mother woke me up every day at four in the morning and lit the oil lamp for me to study in the quiet hours of the morning when my mind was fresh...".

Rao's father was instrumental in inculcating his interest in mathematics.

Rao in his own words: *When I was 11, I could do complicated arithmetical problems without paper and pencil. My father appreciated my interest in mathematics and my good performance in school, and he thought that I should eventually get*

a degree in mathematics and proceed to research to get a doctorate degree. He presented me with the book, Problems for Leelavathi, *a collection of problems set by a mathematician for his daughter, Leelavathi, to solve. He asked me to work out five to ten problems in the book every day. I enjoyed solving these problems, which aroused further interest in me to pursue mathematics. My father also used to tell me about Ramanujan and Noble Laureate C.V. Raman, two giants in mathematics and science in my younger days, and that I should choose them as role models. My father used to refer to me as "my hope, my pride, my joy". Thus, my entry into mathematics resulted from the encouragement I received from my father, my own interest in solving mathematical problems, and my desire to fulfill my father's wish for me.*

In honor of his parents' encouragement and support, Rao instituted a gold medal award in the name of his parents at Andhra University to be given every year to the student graduating with the first rank in the bachelor's degree program in statistics from the university.

Rao developed an interest in research in mathematics at the age of 17 when he joined a Bachelor's honors degree course equivalent to a Master's degree in mathematics at Andhra University, Visakhapatnam, India. He would solve problems posed in the journal, *Mathematics Student*, and his name was often acknowledged in the journal. His teacher, a Cambridge-trained mathematician Dr. Vommi Ramaswami, who was the head of the Mathematics department, became an inspiration in his life. He inculcated in him a spirit of inquiry, which enabled him to pursue research throughout his academic career, extending over a period of 80 years.

KK & SPK: As you mentioned in your interview [1], you started working at the ISI as a regular employee in November 1943, and as a part-time lecturer at Calcutta University in June 1944. You also said that the period from January 1944 to July 1946, before you went to Cambridge, was, perhaps, the most eventful of your research career. At that time, you only had a dual master's degree, one in Mathematics and the other in Statistics. You had not done your Ph.D. research degree at that time, but also you said perhaps those were the most eventful days of your research career. Could you please explain to us why those days were fruitful?

When Rao finished his degree at the age of 19, he wanted to pursue a research career in mathematics and applied for the scholarship for doing research. Unfortunately, the scholarships did not come through due to bureaucratic reasons. He decided to search for a job and found an advertisement for a mathematician for the army survey unit. Unfortunately, the job eluded him. By chance, he met one Mr. Subramaniam, who had come to Calcutta to get training in Statistics, and this chance encounter led him to the Indian Statistical Institute, popularly known as ISI.

In 1941 at the age of 21, Rao joined the one-year training program in Statistics at the ISI, founded by the visionary scientist P.C. Mahalanobis. Mahalanobis had invited two leading statisticians to visit ISI between 1937 and 1940, the most celebrated statistician of the 20th century, Sir. Ronald A. Fisher from the UK and H. Hotteling from the USA. Their visit helped initiate research in the areas of design of experiments, combinatorics, and multivariate analysis. Mahalanobis also collected well-known, talented mathematicians such as R.C. Bose, S.N. Roy, and

K.R. Nayar to teach and do research. Rao's early contact with Bose and Nair created an interest in the design of experiments. Within three months of joining the ISI, Rao published his first research paper with K.R. Nayar in 1941. This was followed by numerous papers on combinatorics with reference to the design of experiments, many with such eminent statisticians and mathematicians as K.R. Nayar, R.C. Bose, and the famous number theorist S. Chowla.

The training course in statistics that Rao was enrolled in when he joined ISI turned into a Master's degree program at Calcutta University, and Rao received his MA in 1943. His MA thesis was in three parts: the first 119 pages on the design of experiments, the second 28 pages on multivariate tests, and the third 42 pages on bivariate distributions. Most of the results of his thesis were published. The third part of his thesis offered a solution to a problem raised by Nobel Laureate in Economics, Ragnar Frisch, and was published in 1947 in *Econometrica*. This was the beginning of Rao's contributions to the field of Econometrics. Examiners of Rao's thesis remarked that the quality of his thesis was equivalent to a Ph.D. degree. His thesis reflects his early interest in four areas of statistics, the design of experiments, linear models, multivariate analysis, and the characterization of probability distribution. These areas kept him busy for the next 80 years.

Rao often says that the period from January 1944 to July 1946, before going to Cambridge where he received his Ph.D. was perhaps the most eventful of his research life. He published over 50 research papers during this period. Several of his groundbreaking research publications, which established his name in the history of statistics as one of the legendary contributors to the field of statistics also are from this period.

KK & SPK: Thank you.

Acknowledgment

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