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C R Rao: A living legend

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Abstract. Professor Calyampudi Radhakrishna Rao - Dr. Rao to most of us - was in the first batch of Master's students in Statistics of the Calcutta University. He graduated with marks that remain unsurpassed. His name is etched in the annals of statistical science through Cramér–Rao bound, Rao–Blackwell theorem and Rao's Score Test. He has been elected to the Fellowship of The Royal Society, awarded the U.S. National Medal of Science and Padma Vibhushan by the Government of India. We celebrate his birth centenary because through his contributions he has elevated statistics as an indispensable applied tool in all walks of life, with firm theoretical foundations.

Keywords. Rao–Blackwellization; Indian Statistical Institute; Bengal Anthropometric Survey.

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In an interview given some years ago, Dr. Calyampudi Radhakrishna Rao had quoted, tongue-in-cheek, one of his mentors, famous statistician and geneticist Ronald A Fisher, "A ballet dancer gets her ovation on the spot, while she is still warm from her efforts. A wit gets his laugh across the table, but a scientist must expect to wait about five years for his laugh. Recognition in science, to the man who has something to give, is, I guess, more just and more certain than in most occupations but it does take time. And when it comes it will probably come from abroad."

Rao went on to say, "The first award I received came from abroad. It was the Fellowship of the Royal Society (FRS)." That was a long time ago in 1967. On June 12th of 2002, he was presented the National Medal of Science by US President George W Bush, for his pioneering contributions to the foundation of statistical theory and multivariate statistical methodology, and their applications, enriching the physical, biological, mathematical, economic and engineering sciences. This is an occasion to celebrate not only for the honour bestowed on the most-respected statistician in the world today, but also because statistics has become an indispensable applied tool in all walks of life through Rao's contributions and efforts.

Chance meeting

Born on September 10, 1920, he was the eighth in a family of 10 children. His father, C D Naidu, who worked in the police department, attached great importance to scholastic

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achievement of his children. His mother, A Laxmikantamma, was a stern disciplinarian. Rao dedicated his book *Statistics and Truth* to her "for instilling in me the quest for knowledge" and "who, in my younger days, 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 the mind is fresh."

C R Rao had an interest in mathematics from an early age. As a six-year-old boy he knew by heart the multiplication tables up to 20 by 20. He won the Chandrasekara Iyer Scholarship, named after C V Raman's father, in physics in Intermediate. However, he decided to pursue a career in mathematics, joined Andhra University and obtained the equivalent of a Master's degree even before he was 20. Pressure from his family forced him to prepare for taking the entrance test for the Indian Civil Service (ICS).

While he had to wait for about 18 months for the test, he decided to take a job and came to Calcutta to face an interview. A chance meeting with a young man in a south Indian hotel on this trip was to change his life. This young man was undergoing training in statistics at the Indian Statistical Institute (ISI). He took him to ISI, which was then located in the Physics Department of the Presidency College. Rao obtained an admission. The year was 1941. His father had just passed away and there was financial stress in the family. However, his elder brother and mother encouraged him to pursue the training at the ISI.

Record marks

"I did not learn much from the courses" during the training programme, Rao said. However, he came in contact with three well-known statisticians, R C Bose, S N Roy and K R Nair, who were all working in the ISI, but did not participate in teaching. Within three months of joining the ISI, Rao wrote his first scientific paper with K R Nair. In July 1941, while he was still a student in the one-year training programme in the ISI, the Master's programme in statistics was started in Calcutta University, with Prasanta Chandra Mahalanobis as a head of the Statistics Department. This was the first degree course in statistics in India. Rao enrolled himself as a student, and graduated in 1943 with a first rank, obtaining 87.5 per cent marks, still a record at Calcutta University. While still a Master's student, he published several papers with R C Bose and K R Nair. His MA dissertation contained original contributions to several areas of statistics – design of experiments, linear models, multivariate analysis and characterization of probability distributions. His seminal contributions have been primarily in these four areas of statistics. They deal with designing an experiment for efficient extraction of information and hypotheses testing from the results of the experiment.

Eventful career

After he obtained MA, Mahalanobis offered Rao a job in the ISI as a technical apprentice in November 1943. In 1946, he sent him to Cambridge to carry out statistical analyses of some data on skeletal material collected by J C Trevor. "The period from January 1944 to July 1946, before going to Cambridge, was, perhaps, the most eventful of my research career," Rao has said. One of the results for which he is most well-known, the Cramér–Rao bound for the variance of an unbiased estimate of parameter, was obtained while he was teaching a course on statistical estimation at Calcutta University in 1944. During this period, he also obtained a process, now known as Rao–Blackwellization, for improving the efficiency of an estimator by the use of a sufficient statistic.

The theorem he proved is known as the Rao–Blackwell theorem. When one wants to obtain knowledge of an unknown parameter of a population (for example, the average height of Bengali adults), and it is not possible to study every member of the population, the knowledge can only be had by studying a small number of individuals drawn from the population. One can then have an approximate, not the exact, knowledge—an estimate. There are several ways of obtaining estimates, but Rao's methods provide ways to obtain highly reliable estimates.

In Cambridge, Rao registered for a Ph.D. under R A Fisher, a founder of modern statistical science. Fisher, of course, did not have a set problem to suggest for Rao's thesis, and asked him to seek his advice only when he "encountered difficulties". Fisher worked in genetics, not in statistics, department, and asked Rao to spend some time in the genetics laboratory where he was trying to map genes on the mouse chromosomes. Rao did so and proposed the Rao's Score Test, which arose in a natural way in estimating the recombination fraction between two genes when data were obtained from different litters of mice. This test is now used in all branches of science, both natural and social.

Rao returned to India in 1948 and became a professor at ISI at the age of 29. In 1964, he assumed Directorship of the ISI and in 1972, after the death of Prasanta Chandra Mahalanobis, became the Director-Secretary of the Institute. He moved to the US in 1978. In 1982, he established the Center of Multivariate Analysis at the University of Pittsburgh. He joined the Pennsylvania State University in 1988.

A biased sample of some pioneering contributions

One of India's foremost anthropologists, Dhirendra Nath Majumdar, and the father of statistical science in India, Prasanta Chandra Mahalanobis, teamed up to conceive and execute a large anthropometric survey of 14 populations of United Provinces, of which 2 were Brahmin groups, 4 were artisan groups and 8 were tribal groups. These anthropometric data were carefully analysed using various innovative statistical methods, some of which were actually invented during the analyses of these data. On Mahalanobis's request, C R Rao carried out much of the statistical analyses. These analyses revealed some important anthropological features [1]. For example, (a) …there is close correspondence between social status and resemblance to the Brahmins, and (b) there are a number of cases in which the physical evidence definitely indicates possible origins contrary to accepted opinion. D N Majumdar and C R Rao [2], under the general guidance of Mahalanobis, undertook another large anthropometric survey; now in Bengal. Like the U.P. anthropometric survey, the Bengal anthropometric survey also yielded many interesting inferences; these include, in Mahalanobis's own words: "One of the important contributions…is the demonstration of regional differences within a social group, that is, between individuals adopting the same caste, tribal or religious name (label), but living in different areas (districts). …This shows that a term like 'Brahmins of Bengal' has to be used with some caution …" He also noted "Another interesting feature…is that sometimes there is closer resemblance between caste groups within a district than between individuals of the same caste group belonging to different districts." Very interestingly, even though these two studies are regarded as landmarks, the architects of these studies – Mahalanobis and Majumdar – became quite disillusioned about the restrictive nature of the studies. In the pages of the Bengal anthropometric survey report, they wrote: (i) "Anthropometry alone cannot tell the tale; we have to supplement by other physical, genetic and serological data …" (Mahalanobis, page 311); and, (ii) "Our experience with anthropometry has not been

convincing, and the blood group variations also need to be looked into …" (Majumdar, page 323). ABO blood grouping was introduced in the Bengal anthropometric survey. C R Rao analysed these serological data and investigated population affinities using the blood group frequencies. However, Majumdar wrote (page 322) "Until we have reinforced our findings by data on other systems, MNS and Rh, we do not think the picture of blood groups based on the ABO system, can give any clue to ethnic origin of the castes in Bengal, or for that matter, of any other part of the country." How true!

Mahalanobis clearly saw value in data that are more genetic in nature. Using anthropometric data, he was unable to answer many questions that interested him deeply. Even though he had moved on to other areas and was contributing to the development of statistical methods in those areas, he retained his interest in finding robust answers to the questions that he himself had sought to find for decades, unsuccessfully as he had himself felt. Prescient that he was, Mahalanobis also felt that genetic data would throw up problems for statisticians to work on, in addition to obtaining answers to basic biological questions. Professor C R Rao's experience in R A Fisher's laboratory in Cambridge working on genetic data in the mouse also supported Mahalanobis's view. Fueled by the enthusiasm of Mahalanobis and Rao, the Indian Statistical Institute soon became the citadel of human genetics activities in India for decades. Driven by the need to graduate to biological markers from morphological measurements for the study of human diversity and affinities, in 1960, C R Rao formed a Haematology Unit and initiated typing of various blood groups from individuals sampled from ethnic groups of India. In 1963, an Anthropometry Unit was formed. And, much later a Human Genetics Unit. Thus, C R Rao was the pioneer of studies on biological diversity in India with a view to understanding their ancestries and relationships. He carried forward the legacy of Mahalanobis and Majumdar.

Wide acclaim

Rao's contributions to mathematics and statistical theory and applications have become part of graduate and postgraduate courses in statistics, econometrics, electrical engineering, and many other disciplines at universities throughout the world. His scholarship has heavily influenced the theory and application of statistics in such diverse fields as anthropology, geology, biology, psychology, social sciences, and national planning. His work in multivariate analysis, for example, is used to improve economic planning, weather prediction, medical diagnosis, tracking the movements of spy planes, and monitoring the course of spacecraft.

Rao has authored or co-authored 14 books and more than 300 research papers. His book *Linear Statistical Inference and its Applications*, published in 1965, has been translated into six languages and has remained as one of the most cited books in science. In his lectures, even on theoretical statistics, he begins by motivating the topic with a practical example. He, therefore, emphasizes that statistical research, even on statistical theory, should largely arise form real-life problems. He has spent his entire career promoting statistics and their usefulness in society. "If there is a problem to be solved, seek statistical advice instead of appointing a committee of experts. Statistics can throw more light than the collective wisdom of the articulate few," he has said.

Rao has categorized creativity into two different kinds. "At its highest level, it is the birth of a new idea or a theory which is qualitatively different from and not conforming to or deducible from any existing paradigm, and which explains a wider set of natural phenomena than any existing theory. There is creativity of another kind at a different

level, of a discovery made within the framework of an existing paradigm but of immense significance in a particular discipline." Rao has excelled in creativity of both kinds, which is why he is the most respected statistician in the world today.

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