Short Biography of C R Rao, F.R.S.

Padma Vibhushan awardee

C. R. Rao is among the world leaders in statistical science over the last six decades. His research, scholarship and professional services have had a profound influence on theory and applications of statistics. Technical terms such as, *Cramer-Rao inequality, Rao-Blackwellization, Rao's Score Test, Fisher-Rao Theorem, Rao distance, and orthogonal arrays (described by Forbes Magazine as "new manthra" for industries)* appear in all standard books on statistics. Two of his papers appear in *Breakthroughs in Statistics* in the last century. C R Rao is the author of 14 books and about 350 research papers. Three of his books have been translated into several European and Chinese and Japanese languages.

Rao received MA degree in mathematics from Andhra University and MA degree in statistics from Calcutta University and started doing research at the ISI (Indian Statistical Institute). He was invited to work on a project at the Cambridge University, UK, which required the statistical methodology he developed at the ISI. Based on the work he did he earned his Ph.D. and Sc.D. degrees of the Cambridge University, and up to date he has received 29 Honorary Doctoral degrees from universities in 17 countries in 6 continents. He held several important positions, as the Director of the Indian Statistical Institute, Jawaharlal Nehru Professor and National Professor in India and University Professor, University of Pittsburgh and Eberly Professor of Statistics and Director of the Center for Multivariate Analysis, Pennsylvania State University in USA. At the age of 84 years, he is still active doing research in statistics, attending conferences and giving lectures.

As the Head and later Director of the Research and Training School at the Indian Statistical Institute for a period of over 40 years, Rao developed research and training programs and produced outstanding students which *"put India not far from the center of the statistical map of the world"*. He supervised the research work leading to Ph.D. degree of 50 students who in turn produced 250 Ph.D.s. During this period he also directed the training programs at the International Statistical Educational Center (ISEC) which led to the development of statistics in the South East Asian region. Rao was the Chairman of a 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 his recommendation ASI (The Asian Statistical Institute) now known as Statistical Institute for Asia and Pacific was established in Tokyo to provide training to statisticians working in government and industrial organizations.

Times of India dated 31 December 1988 chose C R Rao as one of the 10 top scientists of India; the list includes the outstanding scientists, S N Bose, S Ramanujan, Harishchandra, H Khurana, C V Raman, S Chandrasekhar, Salim Ali and G N Ramachandran.

For his pioneering contributions to statistical theory and applications, Rao received numerous awards. He has been elected to the National Academy of Sciences, USA, American Academy of Arts and Science, Royal Society (UK Akademy of Sciences, FRS), Indian National Science Academy, Lithuanian Academy of Sciences and Third World Academy of Sciences. He was made an Honorary Member of the International Statistical Institute, International Biometric Society, Royal Statistical Society (UK), Finnish Statistical Society, Portuguese Statistical Society, Institute of Combinatorics and Applications and Wold Innovation Foundation, and Honorary Life Fellow of King's College, Cambridge, UK. He has been the President of all prestigious statistical associations, the International Statistical Institute, Institute of Mathematical Statistics, USA and the International Biometric Society. He was inducted into

the Hall of Fame of the National Institution for Quality and Reliability, Chennai Branch, for his contributions to industrial statistics and the promotion of quality control programs in Indian industries. At the Berlin conference of the International Statistical Institute held in 2003, Rao received the prestigious *International Mahalanobis Prize for lifetime achievement in statistics and the promotion of best statistical practice.*

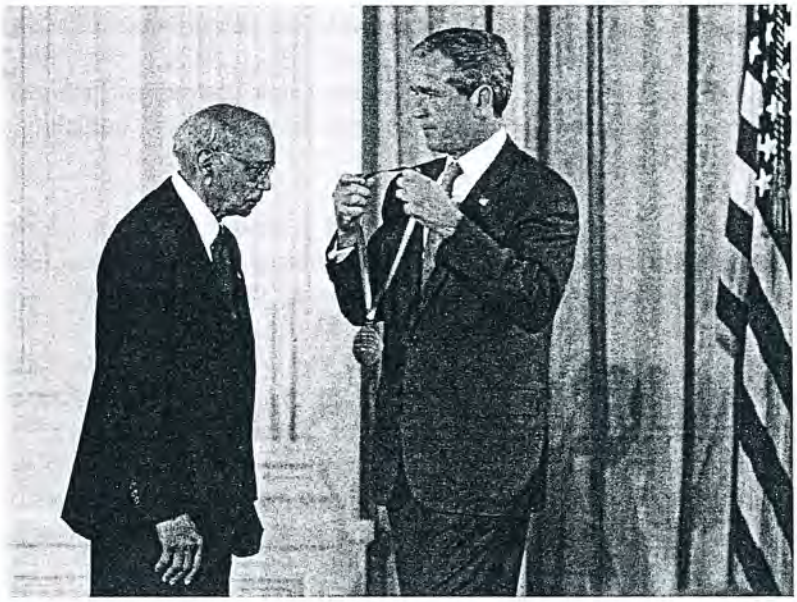
He received numerous medals: Gold Medal of Calcutta University, Wilks Medal of the American Statistical Association, Wilks Army Medal, Guy Medal in Silver of the Royal Statisttical Society, Megnadh Saha Medal and Srinivasa Ramanujan Medal of the Indian National Science Academy, J.C.Bose Gold Medal of Bose Institute and Mahalanobis Centenary Gold Medal of the Indian Science Congress. He received Batnagar award of CSIR (Council of Scientific and Industrial Research, India).

Rao was honored by the President of the USA with the prestigious National Medal of Science "*as a prophet of new age*" with the citation, "*for his pioneering contributions to the foundations of statistical theory and multivariate statistical methodology and their applications, enriching the physical, biological, mathematical, economic and engineering sciences*".

The Government of India honored him with the second highest civilian award, *Padma Vibhushan* for "outstanding contributions to Science and Engineering / Statistics", and also instituted a cash award in honor of C R Rao, *"to be given once in two years to a young statistician for work done during the preceding 3 years in any field of statistics"*.

International conferences were held in USA, India, Canada and Switzerland and special issues of the prestigious journals like *Statistical Planning and Inference, Linear Algebra and its Applications, Sankhya* and several festschrift volumes were published in his honor.

For his outstanding achievements Rao has been honored with the establishment of an Advanced Institute of Mathematics, Statistics and Computer Science (AIMSCS) named after him, in the Osmania University campus, Hyderabad, India.



Professor Rao receiving the prestigious National Medal of Science from the U.S. President

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A Conversation with C. R. Rao

Morris H. DeGroot

Calyampudi Radhakrishna Rao was born on September 10, 1920, in Hadagali, Karnataka State, India. He received an M.A. in mathematics from Andhra University in 1940; an M.A. in statistics from Calcutta University in 1943; a Ph.D. from Cambridge University in 1948, with a thesis entitled "Statistical problems of biological classification"; and an Sc.D. from Cambridge in 1965 on the basis of his published work in statistics as a whole. He joined the Indian Statistical Institute as a statistician in 1944 and became a professor in 1949, the director of the Research and Training School in 1964, the secretary and director of the Institute in 1972, and the Jawaharlal Nehru Professor in 1976. In 1979 he was appointed a University Professor in the Department of Mathematics and Statistics at the University of Pittsburgh. He has been the President of the International Statistical Institute, the Institute of Mathematical Statistics, the International Biometric Society, and the Indian Econometric Society; and since 1964, an editor of *Sankhyā*. He is a Fellow of the Royal Society (FRS) of the United Kingdom; a Foreign Honorary Member of the American Academy of Arts and Science; an Honorary Member of the International Statistical Institute; an Honorary Fellow of the Royal Statistical Society; an Honorary Life Member of the Biometric Society; a Fellow of the Indian National Science Academy and Indian Academy of Sciences; an Honorary Fellow of King's College, Cambridge; and a Founder Fellow of the Third World Academy of Sciences, Trieste. He has received honorary degrees from Andhra University, India, 1967; Leningrad University, U.S.S.R., 1970; Delhi University, India, 1973; Athens University, Greece, 1976; Osmania University, India, 1977; Ohio State University, U.S.A., 1979; Universidad Nacional de San Marcos, Peru, 1982; University of the Philippines, 1983; and University of Tampere, Finland, 1985.

The following conversation took place in his office at the University of Pittsburgh one morning in November 1985.

"THERE WERE NOT MANY OPPORTUNITIES FOR THOSE WITH A DEGREE IN MATHEMATICS TO GET A JOB"

DeGroot: To start at the beginning, tell me a little about your childhood in India, what your home life was like, and how you came to get interested in statistics.

Rao: Well, I come from a family of a kind of landed aristocracy. They had a lot of property and never cared to go and study and try to make a living on the knowledge that they acquired in their studies. However, at one stage they were interested in the legal profession and they all became lawyers and judges and so on.

DeGroot: Who do you mean by "all"?

Rao: My ancestors, my relations. I was, so to say, the first one to get interested in science. I started off with mathematics, but then the war broke out when I was just finishing my master's degree in mathematics and there were not many opportunities for those with a degree in mathematics to get a job. So I tried to get a job in the military service. I applied to the Department of Survey, which is sort of a party to any military expedition. I was disqualified because I was too young and they didn't want me, but that took me to a place called Calcutta. I belonged to the South but I had gone to Calcutta for the interview to get into the military service. At that time I came to know of the Indian Statistical Institute which had been established by Mahalanobis, so I just casually visited the place and talked to people there. They said that statistics was a new subject and if there are no opportunities for a job with a mathematics background, why not come and study statistics.

So I applied for a course of studies at the Indian Statistical Institute and I was admitted. At that time there were no courses in statistics in the universities.

C. R. Rao at age 15

Some universities used to teach statistics as a part of the undergraduate program but not at the postgraduate level. The Indian Statistical Institute was the first place to have what they called a one-year training course in statistics. I took that course, but by the time the course ended Calcutta University had started a master's program in statistics. Mahalanobis said to me, "You join the university and get a formal degree." Since a formal degree is always useful in India as a passport to get jobs, I joined Calcutta University and got a master's degree in statistics. I am one of five first batch students to be awarded an M.S. degree in statistics by an Indian University. So that's how it all began.

"FISHER SAID I MUST WORK ON HIS MICE"

DeGroot: When did you then go to Cambridge and how did that come about?

Rao: After I finished my master's degree, Mahalanobis asked me to work on anthropometric data which had been collected by Dr. D. N. Mazumdar, a well-known anthropologist, in the state of Uttar Pradesh during the 1941 Indian population census. The data were sent to the Indian Statistical Institute for analysis; at that time Mahalanobis had already invented the Mahalanobis distance for studies in anthropology. He assigned the project to me. So my first experience was analyzing data collected on some five thousand individuals, with twenty characters measured on each individual. I produced a report using the Mahalanobis D^2 (distance) in the analysis, and Mahalanobis was very happy with that.

Right at the time when I finished that report, he got a telegram from the anthropological museum in Cambridge saying that a British expedition from Africa had brought a large number of bones and stones and so on. Would he please send one of his students to analyze the data. Mahalanobis replied, "Of course. I have one who is very good in statistics, but he does not know anthropology. So I'll send an anthropologist along with Rao to help you with this project." So we went there and we found a very interesting collection of bones. They had dug out ancient graves, about 1000 years old, from a place called Jebel Moya in North Africa, and brought the skeletal material to the museum in Cambridge. I was actually employed in the Cambridge museum for a couple of years to work on the skeletal material. Incidentally I joined King's College, where Mahalanobis used to be when he was a student, and I also registered for a Ph.D. degree under R. A. Fisher. But Fisher said I must work on his mice, whether it leads to a thesis or not. So I was doing some experiments on mice for R. A. Fisher which involved the mapping of chromosomes, in addition to my work at the Anthropological Museum.

DeGroot: He actually was treating live mice in his experiments?

Rao: Oh, yes. He had a laboratory where he was breeding mice because he was mapping their chromosomes. Lots of mice, maybe thousands. I think we were some ten people working there at that time. He asked me to study the linkage of four genes on a chromosome and find the distances between them. So I was doing that project for R. A. Fisher in the evenings, and in the daytime I was working in the anthropological museum. After two years we wrote the report on this skeletal material which is published as a book by the Cambridge University Press, *Ancient Inhabitants of Jebel Moya* [with R. K. Mukherji and J. C. Trevor, 1955]. The Cambridge anthropologist and my Indian colleague who was an anthropologist also got their Ph.D. theses out of that same project. I think my Indian colleague wrote on the anthropological technique and interpretation of results. The Cambridge anthropologist was also a sociologist, so he looked at the artifacts along with the bones. He made his own conclusions and we put everything together.

DeGroot: And your Ph.D. dissertation?

Rao: My Ph.D. dissertation was based on the theoretical work I did in connection with this project, which is partly in the book. But I had some additional results in my thesis. Fisher's discriminant function was used for classification within two categories, and I developed a method for many categories. I also developed another test. We had to do all the multivariate computations by hand at that time. If I had fifty characters it would be impossible to use all of them, so selection of characters was a major problem. I invented a test of whether it is really necessary to take so many characters. I said, "All right, given a set of measurements, is there further information in an additional set of measurements?" So this is the kind of test which I developed and which went into the thesis. R. A. Fisher was my supervisor. Wishart was an examiner.

"NOW I HAVE THE PRIVILEGE OF WALKING ON THE LAWNS"

DeGroot: Was Fisher much involved in your work?

Rao: Well, he thought my test for additional information was very good because it was an extension of a test he developed in discriminant analysis. That is, if somebody specified the discriminant function, he could examine whether that was the true discriminant function or not. This really involved the idea that the given discriminant function carries all the information; given that function, nothing else is needed. So when I extended that test to a given set of measurements, not necessarily one discriminant function, Fisher was happy. I also mentioned to Fisher that I was working on the problem of classification into more than two categories. I used the Bayesian approach to the problem. He asked me to work along a different line, but I used essentially Bayesian techniques. [Laughs] That's the appropriate thing to do in problems of that kind. Later on I described what you should do when you could not know the prior probabilities. I also created a kind of doubtful region where you can take the position that you are unable to say whether an observation belongs to this group or that group, and described how to operate with that region. That is an abstract of what I did for my thesis.

DeGroot: With both Fisher and Wishart at Cambridge at that time, there must have been a lot of statistical activity around the university.

Rao: That is true, but Fisher was mostly interested in mathematical genetics. So I took various courses in mathematical genetics. I had enough knowledge when I came back to India to direct research work by my students in mathematical genetics. I actually produced three Ph.D.'s in mathematical genetics at that time, very valuable people, but unfortunately they are all working in this country. And Wishart of course was in the school of agriculture. Bartlett was there for a while; then he went to Manchester and Daniels came. About that time the statistical laboratory in Cambridge was established for training statisticians. We had students like Durbin and Bailey and some others. Most of the statisticians at that time were being trained in the statistical laboratory at Cambridge, but it just started in '47 or '48.

DeGroot: Was it unusual for an Indian to be studying at Cambridge at that time?

Rao: No, lots of Indians used to go to Cambridge. It was the place that Indians went for their higher education. But I didn't study in Cambridge in that sense. I was working in Cambridge at the museum, but formally attached to King's College as a research scholar. Later on, King's College honored me by electing me a life fellow. When I was formally enrolled as a research student there, I was not allowed to walk on the lawns in King's College.

DeGroot: I've seen those signs: "Only fellows are allowed to walk on the grass."

Rao: Right. But now I have the privilege of walking on the lawns, and whenever I go there I can stay in the college, have a free dinner, and probably drink as much wine as I want. [Laughs] There are only eleven life fellows at any time. Only if somebody dies do they elect another one.

"ONE STUDENT ASKED, 'WHY DON'T YOU PROVE IT FOR FINITE SAMPLES?'"

DeGroot: Some of the most famous results in statistics have your name on them. One example is the Cramér-Rao inequality, as it is commonly known. I know that Cramér and you did not work on this together. Could you tell me how it came about that your names are paired on this result in this way?

Rao: After I completed my master's degree in 1943, I was asked to teach my juniors in the master's course. There was a shortage of teachers. I think R. C. Bose and S. N. Roy were the two main teachers, and there were a few others.

DeGroot: This was at the Indian Statistical Institute?

Rao: At both the Institute and Calcutta University. You see, when Calcutta University started the master's program they had no teachers, so they borrowed all the teachers from the Indian Statistical Institute. Actually, the lectures were held in the Indian Statistical Institute. Many of our teachers did not know much statistics. They were trying to learn and teach the students. So when I had my formal

C. R. Rao and Harald Cramér, 1978

education, they thought I would be a good teacher and I was asked to teach. I was giving a course on estimation covering all the large-sample properties of maximum likelihood. I proved the asymptotic inequality of R. A. Fisher that the asymptotic variance is not smaller than one divided by the information. Then one student asked, "Why don't you prove it for finite samples?" So I went back home and worked all night. The next day I came up with this inequality, using unbiasedness and the Schwarz inequality. I proved this result in the class in January 1944. Once I started all this, I looked at sufficient statistics. Of course the maximum likelihood estimate is a function of sufficient statistics. Is there an independent small sample justification for sufficient statistics? I thought I must be able to prove some exact properties, and that's how the Rao-Blackwell theorem came up. Which I did two years before Blackwell.

DeGroot: So your work on that type of improvement of an estimator really grew out of your work on inequalities.

Rao: Yes, they are all in the same paper. ["Information and accuracy attainable in the estimation of statistical parameters," *Bull. Calcutta Math. Soc.* **37** (1945) 81–91.] That's in 1945. Blackwell's work was in 1947. I saw Cramér's work on the information inequality when his book on *Mathematical Methods of Statistics* came out in 1946. That is sort of a basic paper mostly arising out of my teaching that course on estimation. I also developed the differential geometric method. I tried to connect Fisher information with a metric in a Riemann space. So my differential geometric approach to estimation is also in the same paper.

DeGroot: That's quite a paper. This differential geometry approach to estimation is now becoming of interest to many statisticians.

Rao: Yes. It's so difficult, nobody liked to work on problems of that kind. I am gratified to see that the geodesic distance I defined using the Fisher information metric is now referred to as Rao distance. Now to complete the story, Fisher came out with second-order properties of a maximum likelihood estimator. That's a very difficult concept and Fisher's investigation lacked some details. Since very difficult computations were involved I tried to modify his definition of second-order efficiency and came out with a quantity which characterizes maximum likelihood estimators in a sense if you go to second-order terms by expanding the asymptotic variance. In the second-order terms, the maximum likelihood estimator has the smallest coefficient. Now that coefficient has been termed the Fisher-Rao inequality by Efron.

DeGroot: That notion of second-order efficiency is very closely associated with you.

Rao: It really started with Fisher. What I did was try to correct Fisher's computations, and also modify his criterion of the minimum loss of information because it is very difficult to work with. That's an exact property which does not really hold, but asymptotically to the second order that idea works.

"FISHER WAS CRITICAL ABOUT NEYMAN"

DeGroot: Who do you feel have been the major influences both on your life and on your career?

Rao: I would say Professor Mahalanobis in India. His whole idea was that statistics must have a purpose. So he said, don't try to solve problems in mathematical statistics. First look at the data and see what the problems are, and then try to develop the appropriate methodology for that kind of data. The next is, of course, R. A. Fisher. When I went to work with him, I first told him, "I have studied mathematical statistics; I have also done some research. Would you give me a problem that I could work for my thesis?"—as students do in this country. Fisher said, "No, the problem must be yours. I can help you to solve the problem." [Laughs]

Also, I wrote a paper in mathematical genetics and said that the method I developed was superior to one that somebody else gave, but Fisher said, "I won't read your paper unless you do some computations. Gather the data and compare what your method gives with what the other method gives, and then come with a paper and I shall read it." This is the kind of advice which I think was very useful later in my consultation work and also in my own research in mathematical statistics. I always develop methodology from the data given to me for analysis rather than look at other's work and try to extend it in terms of mathematics.

I used to meet Wishart frequently when I was in Cambridge because we used to discuss lots of problems. That was also useful, but the two people who provided inspiration for me are R. A. Fisher and Mahalanobis. Of course, at that time Neyman's work was becoming popular and everybody had to read that. So I read a lot of work that Neyman did and I think he was also responsible for my getting into the current research at that time in testing of hypotheses.

DeGroot: Did Fisher ever discuss Neyman's work with you?

Rao: Yes. He was critical about Neyman. Whenever I had discussions and wanted to use Neyman's ideas in solving some of the problems, Fisher always discouraged me from doing that. Actually, I now feel that I could have done some work which is currently popular if I had used Neyman's ideas in those days. I was not reluctant to use Neyman's ideas, but I did not probably because of Fisher's influence.

DeGroot: Was Fisher generally pretty good about reading things that you would give him?

Rao: Oh, yes. He would take great interest. And then he would read and comment on it. He was also a very exciting teacher. Not many could follow what he was teaching; but if one tried to see what he was saying, he was an inspiring teacher. I also used to attend his seminars and they were very good. But most of the time when I was at Cambridge I used to help him in his genetic experiments.

"LINNIK SUGGESTED THAT WE ALL WRITE A BOOK TOGETHER ON CHARACTERIZATION PROBLEMS"

DeGroot: You've published, according to my count, nine books and about 230 papers. Your book *Linear Statistical Inference and Its Applications* is of course widely known. [Second Edition, John Wiley, New York, 1973] I've always felt that the title was something of a misnomer because that book really covers much more than linear statistical inference. In fact, it covers much of what is in a standard graduate course in statistical theory.

Rao: Actually, I had a different title but the referees suggested this title because it would compete better with other books with similar titles at that time. So I said, "OK. From the commercial point of view, if that title will sell very well then you may choose that title." [Laughs] It had a different title to begin with.

DeGroot: What was your original title?

Rao: Advanced Statistics or something like that. Actually, when I wrote my first book and called it *Advanced Statistical Methods in Biometric Research* [First Edition, John Wiley, New York, 1952; Reprint, Haffner, New York, 1974], I really summarized what I did in Cambridge on the anthropological material. Most of the examples there are all from anthropometric data. People wondered how I suddenly introduced data on head length and head breadth and so on in between theoretical discussions. But the major emphasis in that book is the applications of statistical methodology to univariate and multivariate data. It's slightly more theoretical than R. A. Fisher's book, but because the title said biometric methods the statisticians were not attracted to it.

DeGroot: Yes, that's another book whose title is much narrower than the content of the book—where you cover much more material.

Rao: Well, I thought I was discussing some biological problems and so the title was appropriate.

DeGroot: I remember using that book when I was a student just for learning about statistical theory generally.

Rao: My *Linear Statistical Inference* is really only a mathematical version of that book, I think.

DeGroot: I see. Well, have you been giving any thought to a new edition of *Linear Statistical Inference*?

Rao: When I try to review the book, I find that much has happened since the second edition came out, so I was thinking of working on a third edition not as a single volume but maybe as a couple of volumes. It depends on how much time I have because in this country there is a lot of pressure for writing papers, getting grants, writing more papers for the grants, and so on. [Laughs] So I don't have much time to think of revising the book. But I have given a variety of courses in this country and made some notes which would be useful in making a third edition of the book.

DeGroot: I'm also curious about your book with Kagan and Linnik, *Characterization Problems of Mathematical Statistics* [John Wiley, New York, 1973]. That book was published first in Russia and I first saw it in the Russian language edition when Kagan sent me a copy. Then subsequently it was translated into English. How did that collaboration with the Russians come about?

Rao: I think I was interested in characterization problems right from my student days. There was a paper by Ragnar Frisch in which the following problem was proposed: If there are two random variables X and Y where $X = \psi + \eta$ and $Y = \psi + \upsilon$, so there is a common variable ψ, under what condition is the regression of X on Y linear? X and Y have only one common variable ψ; the other variables η and υ are independent. I gave a general solution to this problem in my thesis as a partial requirement for the M.S. degree. This was ultimately published in *Econometrica* in 1947 [**15** 245–249; Correction, **17** 212].

Then when I had my research students, I gave them problems on characterization for their thesis work. I was doing some work on characterization right before

C. R. Rao, A. N. Kolmogorov, and P. C. Mahalanobis, Calcutta, 1962

Linnik's first visit to India in 1955. I told him what I was doing, and being a mathematician he liked the idea. When he went back he started working on very complicated characterization problems using ideas of number theory and so on. It was very surprising. I was visiting the Soviet Union frequently at that time and we used to meet. I attended the first mathematics conference held in the Soviet Union after the war in 1956. At that time I met other acquaintances of Linnik. Linnik introduced me to his student Kagan subsequently. As I said, at that time Linnik used number theory ideas and he was trying to characterize the normal distribution by the identical distribution of two linear statistics. Then I took Linnik's ideas and tried to extend his methods to problems involving linear statistics but under different conditions and so on. During a subsequent meeting with Linnik, he suggested that we all write a book together on characterization problems in mathematical statistics. We decided how many chapters I would write and what Kagan and Linnik would write. I think within a year or so, we put our material together. I wrote in English and they translated it into Russian. They kept me informed of what they were doing.

DeGroot: So you would communicate with each other in English.

Rao: Yes. Linnik knew English and Kagan knows English. We formed a good team and were able to complete the work within a year or so.

"YOU CAN SAY ANYTHING IN AN ABSTRACT"

DeGroot: Linnik must have died just about the time that the book came out.

Rao: Yes, he died in June '72. Linnik and Kagan also translated my *Linear Statistical Inference.*

DeGroot: That's very interesting. They were also influential in translating my decision theory book into Russian.

Rao: There's one interesting thing I must tell you about the translation of my *Linear Statistical Inference.* I had made the comment that in the Fisher-Behrens problem, there is no similar-region test when σ_1 and σ_2 are different. Linnik had proved that in a certain class a similar-region test actually exists. So Linnik said my statement was wrong and they just modified it in the Russian translation. In this connection, when Wilks was alive I discovered that he had an abstract in *The Annals of Mathematical Statistics* where he claimed that no similar-region test exists. So I wrote to Wilks in the 50s or so, asking him to please send me the proof or tell me how he had done it. Wilks replied that this was done during the wartime, that his office was moved after the war and the whole folder containing the proof of this proposition was lost in the process, and that he does not recall how he did it. You can look at the abstract by Wilks [**11** 475–476, 1940.]

DeGroot: Wow!

Rao: There was another incident recently in which somebody claimed priority because he had mentioned a result slightly less general than mine in an abstract in the *Annals.* You can say anything in an abstract. If it is right, you can claim credit and priority.

DeGroot: Yes. Take a chance; maybe it will be right. There is no serious screening of abstracts. I think that's OK, as long as everyone realizes that the results are not necessarily correct or original.

Rao: Actually when that person wrote the full paper on the basis of the abstract, I was a referee and it turned out that this result was also not correct as stated.

DeGroot: Do you still visit the Soviet Union?

Rao: I was there last year for the conference at Vilnius. As Director of the Indian Statistical Institute, I was very much involved in the exchange of scientists between the Soviet Academy and the Indian Statistical Institute. In fact, we had a separate agreement between us for the exchange of up to eight scientists every year on either side. So we send our people and they still come to the Institute.

DeGroot: What is your impression of the political situation in the Soviet Union? Have you seen any changes through the years?

Rao: Well, there was some change since the fifties. I think that in matters of science they now just do the same thing as the rest of the world.

DeGroot: Do you see Kagan when you are there? I know he has been trying to emigrate for several years.

Rao: Not this time. He was not at the conference that I attended. The last I saw him was in 1976. But I am in correspondence with him. We still try to collaborate a bit. I used to like the Leningrad group because whenever I was there I would give seminars and they would tell me what they were doing. I used to give them some problems and they would solve them immediately. [Laughs] So there were some papers on problems posed by Rao. It was quite a good group. Ibragimov and others were there. I am an honorary professor of Leningrad University. That came along with the honorary doctorate I got from there. So I always visit the university when I go there.

DeGroot: Do you have royalties in the Soviet Union?

Rao: Yes, I have royalties for the translation of *Linear Statistical Inference* and for *Characterization Problems.*

DeGroot: I found it difficult to spend my royalties when I was there. How do you spend yours?

Rao: Generally when I go there I just call my friends and give them a party. [Laughs] I still have unspent money there because when I go as a visitor the Soviet Academy pays all my expenses. So this money is in the bank. By the way, they give interest on money. I put the money in the bank and the second time I went to find out how much money I had, I found some amount of money added in red ink. They said that was my interest.

"IF WE HAVE GOOD VISITORS, ONE CAN WORK FASTER"

DeGroot: What are your favorite publications among your many books and papers? Do you have any particular favorites that you enjoyed doing, and which ones do you think have been the most influential?

Rao: I enjoyed doing my applied work, especially the applications in anthropology, but that work gave rise to the development of methodology in multivariate analysis. I think the papers where the work I have done was followed up by many others are my early papers on estimation. Then there are papers on second-order efficiency, and now the papers on differential geometry that are coming up. So I am happy because somebody is following up the work I initiated. A second set of papers I like are mostly in the analysis of repeated measurements and in singular linear models, i.e., when the design and covariance matrices are deficient in rank. I developed generalized inverses of matrices for dealing with such problems. My work on orthogonal arrays is widely used in industrial experimentation, and has led to important inequalities in coding theory. I found that special courses on orthogonal arrays are given in this country. In 1947 (*Proc. Cambridge Philos. Soc.* **44** 50–57) I introduced two general asymptotic test criteria called score tests for simple and composite hypotheses as alternatives to Wald's tests. I find that my score test for composite hypotheses has become entrenched in the econometrics literature under a fancier name, the Langrangian Multiplier Test. So those are a few papers which I like and which have received some attention.

DeGroot: What are your current research interests?

Rao: I am working on two types of problems: One is prediction, not in time series but in repeated measurements like growth models. I think I have done some fairly useful work for applications in practice. And now I am working on what is really discrimination but what electrical engineers call signal detection. Problems like when one can recognize that a real signal is coming and not just pure noise.

DeGroot: That's a classical problem.

Rao: Yes, that's right. But there are some new problems that arise in this connection which we are currently solving. There is also another problem. For instance, in a discrimination problem we essentially estimate a discriminant function on the basis of data, and then we use this for discriminating the future observations. So the real performance of the estimated discriminant function has not been properly studied in the past, because when they studied the properties of the discriminant function they always studied them on the average; that is, the properties if you would go on estimating the discriminant function each time with fresh data, and then apply these estimates. But in a real problem you get stuck with a particular estimate of the discriminant function for use in discriminating future observations.

DeGroot: You really want the properties conditionally on the given estimate.

Rao: Yes, and to know how it's going to perform in the future—how we can estimate its performance from the available data itself.

DeGroot: Sounds Bayesian to me.

Rao: Yes. So that's the new type of problem which we are trying to work on, and already we have written some papers on that subject.

DeGroot: Who are the "we"?

Rao: Visitors who come here who are assigned to the project on signal detection that we have. So I am doing this work in collaboration with visitors because that way we can work faster. Of course, the problems are conceived and some groundwork is done before the visitors come. To write, say, two papers in a month or two months is not unusual although it is strenuous. Probably one writes a paper once in four months or six months in the normal course. But if we have good visitors who are good in mathematics and have similar interests, then one can work faster.

"THE PRIME MINISTER USED TO LIKE US"

DeGroot: How did you get to know Nehru and Indira Gandhi?

Rao: Well, statistics was originally with the Prime Minister's office; that is, all decisions about the Indian Statistical Institute and the development of statistics were taken directly by the Prime Minister for a long time. It was not under any particular ministry. Probably no ministry wanted statistics. So whenever we wanted to discuss problems or ask for fresh grants or make proposals for the development of statistics in India, we used to go to the Prime Minister. Jawaharlal Nehru was the Prime Minister at that time. So we met him very often to discuss problems of statistics and he was very helpful. Actually, Jawaharlal Nehru was responsible for recognizing the Indian Statistical Institute as an institute of national importance. He moved a bill in the parliament declaring the Indian Statistical Institute an institute of national

C. R. Rao and Indira Gandhi, 1967

importance and giving it a charter to award degrees. Formerly we had been training statisticians, giving them courses both in the theory and the applications of statistics, but we were not allowed to give degrees. We used to give a diploma, but after this bill was passed in the parliament we started giving B.S., M.S., and Ph.D. degrees in statistics.

DeGroot: When was that?

Rao: Oh, this was in '60 or '61. Before that, when we did not have the charter to give degrees, all of our students who were doing research with us had to submit their theses to some university in India, either Calcutta University or Bombay University. We were recognized as supervisors for theses, but the Institute could not give them degrees. The Prime Minister used to like us, and he gave us a lot of support by giving us as much money as we wanted for educational, research, and consulting purposes. And then after Nehru died, Indira Gandhi took his position and we continued our association with her. She knew Mahalanobis and the Indian Statistical Institute he founded because of her father's relationship with the Institute and the help he had given to the Institute.

DeGroot: Have you had other relationships with the Indian government?

Rao: Actually, the Indian Statistical Institute was responsible for drafting one of the five-year plans.

DeGroot: The economic plans?

Rao: Yes. Much of the second plan was drafted by the Indian Statistical Institute under the guidance of Mahalanobis.

DeGroot: When was that?

Rao: 1954 or so. So we continued our association with the planning commission, and the Prime Minister is the chairman of the planning commission. There are a large number of projects which we did for the planning commission. As a matter of fact, the Indian Statistical Institute branch at Delhi was located in the planning commission for a long time. It's only recently, when we built a new campus for the Indian Statistical Institute which was opened by Indira Gandhi, that we moved from the planning commission to our own premises. So we were very much attached to the government because of our involvement in working on projects for the planning commission. And I used to work on some committees on statistics formed by the Prime Minister.

DeGroot: Do you know the present Prime Minister?

Rao: I don't know him because he was not in

politics when we were in contact with the Prime Minister's office. Occasionally we saw his brother, Sanjay, but not Rajiv.

"THE WORKERS HAD WRONG IDEAS ABOUT COMPUTERS"

DeGroot: I'm sure you've had many interesting and fascinating experiences during your time at the Indian Statistical Institute. I remember hearing about some of the problems that you had when you took over as director in Calcutta. Could you tell me a little bit about your experiences during that period?

Rao: The Indian Statistical Institute is a very large organization. It employs 3000 people. There are lots of divisions engaged in working on different kinds of problems. Our idea was that everybody must use statistical ideas in their investigations although they are working on their own scientific problems. So that was a difficult job, to keep in touch with the various scientists working on different kinds of problems, to see to what extent they were using statistical methods in their investigations and to give them proper advice. There was also the problem of bringing scientists working in different disciplines together to work on some kind of common projects. For instance, when I sent a team for a demographic survey, I included some physical anthropologists who would go and do the measurements, sociologists to do studies on families and relationships, and seriologists to take blood samples and do the blood grouping and so on. So this was the most difficult problem and I succeeded in most cases and failed in other cases.

We had some trouble when we brought in the computers. The Indian Statistical Institute was the first organization in India to acquire digital computers. We had one computer brought from the Soviet Union in '55 and another digital computer brought from Great Britain. But the workers in India did not like our introduction of computers in a big way. They had wrong ideas about computers. They thought it would affect their employment opportunities.

DeGroot: Are the workers unionized?

Rao: Oh yes, we have very strong unions in every organization in India. Let me continue. I had developed an interest in computers when I was working in Urbana-Champaign at the University of Illinois in 1953–1954. I think that university had the first digital computer, called Illiac, and I used to work on that computer. I took a course on programming. So I was probably the first programmer of India. I was one of the few who could do programming using machine language. The University of Illinois gave me two students to develop computer programs for statistical methods at that time. So I made them work, and in order to understand those programs I learned computer programming myself. Nowadays it's easy, but at that time to use sixteen instructions to write the whole formula was a difficult problem. So I had a lot of interest in computers and I really wanted to develop computers in India, which was not possible under the conditions prevailing in India. That was a big disappointment for me. We lost the opportunity to do certain kinds of research or develop methodology based on complex computations.

DeGroot: I seem to remember that at about that time you moved from Calcutta to Delhi.

Rao: No, I moved from Calcutta to Delhi much later.

DeGroot: It was unrelated?

Rao: It was unrelated. Because I was not finding much time for doing research in Calcutta, I moved over to Delhi and asked somebody to share the administrative responsibilities in Calcutta. It was purely to get time to do research that I moved to Delhi.

"THE INDIAN STATISTICAL INSTITUTE IS REALLY A FANTASTIC PLACE"

DeGroot: What are some of your more pleasant recollections of your tenure there?

Rao: The Indian Statistical Institute is really a fantastic place. It used to attract famous scientists from all over the world. For instance, Norbert Wiener worked at the Institute for six months in, I think, '52 or '53. And J. B. S. Haldane was a regular employee of the Indian Statistical Institute. He was there for five years, and I was formally head of the department where Haldane was working. Mrs. Haldane also used to work there. A number of famous economists visited the Indian Statistical Institute: Ragnar Frisch, Simon Kuznets, Richard Stone, who got the Nobel Prize in Economics last year; and some of the presidential advisors in economics from the U.S.A. That tall economist, John Kenneth Galbraith, spent three months at the Indian Statistical Institute. On occasions I used to go for a walk with him. He is so tall I had to look up in order to carry on a conversation with him. Oscar Lange from Poland also visited the Indian Statistical Institute. And the Indian Statistical Institute was declared a show piece which every visitor to Calcutta must visit. So Kissinger came to the Indian Statistical Institute. I have nice photos shaking hands with Kissinger and Mrs. Kissinger, and taking him around the Institute and explaining to him what we are doing. Premiers of all countries would come—Ho Chi Minh, Chou En-lai. It was quite an interesting place. And lots of scientists; at any point of time there would be ten or twelve foreign scientists visiting the Institute.

DeGroot: I remember your telling me that it's the only statistical institute in the world that has a dinosaur in it.

Rao: Oh yes, there is a geological department, and dinosaurs were discovered for the first time in India by the Indian Statistical Institute. We have a geological museum. By the way, Jawaharlal Nehru was a geologist. He studied geology when he was a student at Cambridge, so he had a lot of interest in geology. He was very much excited when we found the dinosaur. And so when the first bone, the dinosaur's thigh bone, was discovered somewhere in South India we took the dinosaur bone all the way to Delhi to show it to Nehru.

DeGroot: There seems to be a tradition in India of mathematically-talented young people going into statistics rather than into other branches of mathematics proper. Is that a correct impression, and if so, how do you think that came about?

Rao: I think that was true only for some time when there were no jobs for those who studied mathematics. They used to study mathematics just for the love of mathematics. Generally, Indians are more abstract minded; they are not practical-oriented people. That's the reason why Indians did not contribute much to science in the past. But physics, metaphysics, philosophy, mathematics, they just love, because they think that anything can be proved by argument. [Laughs] Of course, in mathematics there are axioms, and therefore argument is relevant. But not in areas where there are no fundamental axioms. But when they found that there were no good jobs in mathematics and that statistics was a developing field, many mathematicians thought it logical to study statistics! And that's the reason why a lot of good statisticians developed in the late '40s and '50s in India.

DeGroot: Is the situation still the same?

Rao: No, nowadays we are not getting such good students for statistics as we used to get in the past. Probably there are areas of applied physics and chemistry which are more attractive now. Some students still go for mathematics. So it was only a temporary phenomenon that all good mathematicians came to statistics. That was true in this country, too.

"I THOUGHT I SHOULD VISIT THE STATES FOR JUST ONE YEAR"

DeGroot: What prompted you to accept a faculty position in the United States here at the University of Pittsburgh in 1979? You had, of course, visited the United States often.

Rao: Yes, several times. And I also worked briefly at various universities in the United States. Actually, I had retired from the Indian Statistical Institute, but they gave me another position—a special chair called the Jawaharlal Nehru Professorship.

DeGroot: That chair was awarded upon your retirement as director?

Rao: Yes. It was approved by the Prime Minister, Indira Gandhi. But after retirement I thought I should visit the States for just one year. So I took a visiting professorship at the Ohio State University, Columbus. At that time my son, who was studying engineering in India, came to the United States to visit me. I was briefly in Pittsburgh, and I think he met the Dean and the Dean said that he could continue his engineering courses here. He already had done three years in India. So he met the engineering faculty; they gave him credit for what he had done and told him that if he studied for another two years here, he would get the same kind of degree, a Bachelor's in Engineering, that he would get in India. So he accepted admission here and did not go back. A few days later the Dean sent word through the chairman of the Math Department here asking whether I would take a job here. One of the attractions was that I wouldn't have to pay tuition for my son if I took the job. So I said maybe, temporarily for two years, I will accept, because I have my job in India; I have to get back. He said, "You take the job. I'll give it to you on a permanent basis. You can go back whenever you like, or you can work part of the time here and part of the time in India."

DeGroot: That sounds like an offer you couldn't refuse. Have you been dividing your time going back and forth?

Rao: Not much. I have been spending most of my time in Pittsburgh because this department itself needed some development. I think that when I joined they didn't have many graduate students in statistics. I even heard that they were going to close down their graduate studies in statistics. But over the course of the past five years we tried to develop advanced courses in statistics, and to increase the number of graduate students, and also to write some papers. I think the department is now very well rated.

"I USED TO WATCH WHAT THE GARDENERS WERE DOING AND DIRECT THEIR WORK"

DeGroot: During the years that you have been in Pittsburgh, I've come to learn of your many talents outside of statistics such as gardening, photography, and cooking. Let's take these one at a time. Would you tell me about your interest in gardening?

Rao: Well, I've always loved gardening. I used to work in my garden in India. The Indian Statistical Institute has a big campus and there's a lot of area for gardening. I think they have about 50 gardeners working there. So I used to go around early in the morning to watch what they are doing and to direct their work. I used to advise them on the type of flower plants they should grow, give them a design for planting trees, and indicate where they should grow vegetables. So I always took an interest in gardening. But I never

allowed anybody to cut the flowers from the plants, so everybody had a grudge against me. [Laughs] They used to come stealthily and cut some flowers in the evenings. But I used to go down to the garden several times a day—in the morning, at lunch time, and in the evening. So when I came here I found a small space, but it is too small a place for doing gardening compared to what I had at the Indian Statistical Institute.

DeGroot: A small space in your backyard here?

Rao: Yes. I tried to grow some exotic vegetables from India, oriental vegetables. It was very successful, and I think I had better crops here than I had in India. That is because I used fertilizers here. We don't have good fertilizers in India; I used farmyard manure there.

DeGroot: Do you perform statistical experiments in your garden and analyze the data?

Rao: Yes, I used to. Here also I tried one experiment, but in India I generally experimented. For instance, one of the experiments which I was doing in collaboration with my colleague T. A. Davis at the time of my retirement was the following: The cowpea is a creeper. It is a plant which twines on the right when it grows. That is, it grows up around a pole in a right-spiral. At the Indian Statistical Institute, Davis had already done some work on the right-handed and left-handed palms. Some palms grow in a right-spiral and some grow the other way, i.e., the positions of successive leaves as a palm grows form a right-handed or a left-handed spiral. It's a very nice phenomenon. You know how a flower unfolds. For some flowers the petal to the right will be below the petal to its left, but in some flowers it's the other way, the petal to the right is above the petal to the left. That shows that some flowers unfold in a clockwise direction and some flowers unfold the other way. So there are left flowers and right flowers. We were very much interested in knowing what causes this difference among flowers. So we used to count. We had a team of students who used to go and count how many flowers on a plant are of the left and right kinds.

DeGroot: On the same plant?

Rao: On the same plant; even on the same branch. So there is some random mechanism going on which causes this. Davis made these observations on thousands and thousands of flowers and also on palm trees for left-right spirality. We also studied the yields of these palm trees, and we found that the left-handed palms gave greater yield than the right-handed palms.

So we said kill all the rightists. By selective plantation, choosing only the left-handed palms from the nursery and growing them, you can possibly increase the yield by 5 to 10%. This creeper, the cowpea, gave us a lot of trouble. It always used to grow on the right side. We grew a large number of plants and found that all of them were growing in the right-spiral. And I was told there are some creepers which always grow in the left-spiral. So we used to go early in the morning and pull the growing tips from the right to the left direction and tie them with ropes to the poles to force the plants to change their habit. Sometimes we used to stretch the growing top straight and tie it up and see the next morning where it had grown. But it always used to have a right tendency. We tried to measure the yields of the cowpeas that were forced to go left but unfortunately some damage might have been caused to the plants because we were handling them. So we did not think that the data we collected gave any evidence that forcibly making a plant grow on the left increased the yield. [Laughs] I had a garden where we used to do experiments of this kind right in front of the place where I was staying. It is quite exciting to do things like this and to get students interested in this phenomenon.

"WE USED TO DO ALL THE COOKING FOR DAYS AND DAYS"

DeGroot: What about your interest in photography?

Rao: Oh, I have some interest in photography. Some of my pictures are very good; I used to win some prizes by submitting them in competitions.

DeGroot: Do you just take pictures where you find them?

Rao: Yes, wherever. I don't really have time to especially go on photographic expeditions. When I just go out and feel like taking my camera, I take pictures. But not on any planned basis. If I had done that, maybe I would have made a lot more pictures; but I never did.

DeGroot: Do you usually take your camera with you when you travel?

Rao: Not generally, but sometimes I take it. It depends on my mood. I also took a lot of movies when I was young. But it's a very expensive hobby. I could do that only when I came to this country and gave a lecture and earned $50 or $100. [Laughs] Of course in India I could never take pictures because we don't have the proper film; and developing and printing costs are very high. And I didn't have a good camera. Well, I took all my good pictures with very cheap cameras costing five to ten dollars. We really don't have opportunities for this kind of hobby back in India.

DeGroot: So this is more of an American development with you?

Rao: I don't know the current statistics; an average American takes a thousand pictures a year or something like that. [Laughs] That's how Kodak flourishes.

C. R. Rao at the University of Tampere after receiving an honorary doctorate, May 1985

But I am also interested in cultural activities like dance and music. We put our daughter in dance school very early because of our own interest in dancing.

DeGroot: I've seen her dance and she's an excellent dancer.

Rao: Yes, she's a very good dancer. She runs a dance school in Buffalo.

DeGroot: Does she do any Western dancing?

Rao: She does a little bit of Western dancing but mainly she does Indian classical dancing. I developed a new dance academy in Delhi and was its president. We covered some neglected areas of dancing.

DeGroot: So you are quite knowledgable about Indian classical dance and Indian classical music.

Rao: More dance than music, because dance also has the visual effect.

DeGroot: What about Indian classical cooking?

Rao: Well, traditionally I used to like cooking because I used to help my mother cook. My mother also had other interests and she used to visit other places. At that time there were only boys and my father in the house, and we used to do all the cooking for days and days. My wife comes from a family where there was only one girl and five brothers, so she was very much pampered and did not know cooking. So all the cooking she now knows, she learnt from me. [Laughs] My son is a very good cook. So it seems to me that there's some gene in the family for this culinary art. I think basically that cooking is an art, so I think that it's an interest in art.

DeGroot: Are any of your brothers or sisters interested in statistics or other mathematical things?

Rao: My brothers and sisters were all basically very intelligent people. I had an elder brother who was a doctor who was phenomenal. He had a wonderful memory. If you gave him 150 names, he could just read them once and then repeat all those names. One brother was an engineer, quite a good one. You see, we are a family of ten, so many of them died. Another was in commerce. One of my sisters was a poet; she wrote poetry in Telugu. And one was really a business woman; she did a lot of business and made a lot of property along with her husband. They didn't have any formal education because girls did not study years ago in India. So it was all an innate thing. My sister who was a poet just studied by herself and started writing poetry. But they were not mathematicians, except for the engineer who had to study some mathematics.

"THE TWO GREAT METHODOLOGIES IN STATISTICS ARE SAMPLE SURVEYS AND DESIGN OF EXPERIMENTS"

DeGroot: Are there other things that you like to do when you are not doing statistics?

Rao: Well, as I grow old I find that there's not much time to do many things. But in the next two or three years I may be visiting the third world countries and helping them in developing research in statistics. This is an assignment that the Third World Academy of Science, of which I am founder fellow, is trying to give me. I have not replied to their letter yet because I am not sure how my health will be in the coming years. But this is something which I would like to do because I know the third world countries are not developing basic research. They are dependent on foreign countries for all technological improvements, which is not good in the long run. That's the reason why we founded the Third World Academy. In addition, I may have some assignments in India which would keep me busy and occupied for a long time to come.

DeGroot: What do you think are the important trends in contemporary statistics? Where do you see the field going? Where do you think it should be going?

Rao: Those are questions about which I am con-

stantly thinking. I believe the two great methodologies in statistics are sample surveys, which is essentially collecting existing information, and design of experiments, where you generate observations to provide information on some given questions. Different types of data analyses are, of course, then applied depending upon what the statistician thinks is the right thing to do. They are not as fundamental as the data which are collected through principles of design and sample surveys. If data are good, results should be obvious; the analysis is only to convince somebody that there is a real difference and so on.

DeGroot: So you are saying that with a good design or a good survey, the answer should be obvious without doing any complicated analysis.

Rao: The analysis is only to make sure that we are not deceived by what we are seeing. Much of it should be obvious by looking at the data or by simple analysis. Even graphics is very important. That's the reason why R. A. Fisher emphasized graphical representation of data as part of statistical analysis. Although many people are not aware of this, the very first chapter of his book, *Statistical Methods for Research Workers*, is graphics. Nobody reads that although it is a very nice chapter. So I think we should be doing more graphical analysis, especially with the help of the computers we have. We can do things now, which we could not previously do, with transformations of variables and graphics. Further research in sample surveys and design of experiments to refine the already refined methods in these two areas would be helpful.

Then we should be developing some routine methods of statistics for applications, like the quality control methods and what Shewhart did in industry: a simple and efficient way of presenting data which enables them to see whether everything is OK or something is going wrong, or whether there is scope for improvement. There is a great need for developing simple techniques for routine applications in other areas to improve the overall efficiency of goods we produce and services we offer.

"HOW DOES THE DOCTOR DECIDE WHETHER THERE IS SOMETHING PATHOLOGICAL OR NOT?"

DeGroot: The medical area is one example.

Rao: Yes, there are many challenging problems in applications of statistics to medicine. We don't seem to have done much in that area. So this is where we should be working, along with the medical doctors, to try to see how statistics can be applied to improve diagnosis, treatment, monitoring the effect of drugs on the patients, and so on. Statistics is used in a slightly different way in problems of bioassays and the screening of drugs. But I think a lot remains to be done in medical diagnosis. I don't know whether I told you this story or not. When I was working at Johns Hopkins—that's the place where many famous doctors are—I went to a doctor because I felt some uneasiness in my stomach. He made a large number of tests and asked me what was wrong with me. I said that the Indian doctors told me that the food I take does not stay in the stomach long enough. It gets into the intestines within half an hour but normally, in other cases, it takes one-and-a-half hours or so.

So he said "The fact that the food stays only for half an hour doesn't mean there is something wrong with you. You know, if you take a set of normal individuals and find how long the food stays in the stomach for each individual, that's a variable and it is normally distributed." *He* tells *me*. [Laughs] So the fact that you are a member of that normal group having a small value doesn't mean there is something wrong with you. If a person is five feet tall, that's not pathological; some healthy individuals are five feet high and some are six feet high, and so on. So if it's not by looking at the battery of tests, how does the doctor decide whether there is something pathological or not? Suppose that with all those abnormal values, the patient looks all right. Does that mean there is something wrong with him? So it's probably a combination of the tests and the doctor's evaluation of the patient's general condition.

As soon as you go to the doctor he asks what is wrong with you, and he takes a case history. Are you all right? Are you able to think? Are you able to write papers? Are you able to walk? Are you able to drink? You see, if you do all this with your bad cholesterol, then it's OK, that's normal with you. So diagnostic tests like measurements on the blood chemistry are not by themselves enough to make a diagnosis. The patient's condition must also be an input into it. The question is how to put them together and come up with a diagnosis. It's an art for the doctor. Probably in the past nobody made any tests. If you went and told the doctor that you had a fever and other things, he felt your pulse and prescribed a medicine. So the general condition of the individual is probably far more important to the diagnosis than what the diagnostic tests reveal. So I am working on this kind of problem: how to put together the results of tests and the doctor's judgment of the patient's case history, and other prior evidence, which may be personal and subjective, and come to the right diagnosis.

DeGroot: That's great.

Rao: So there should be more routine applications of statistics wherever they are needed, and we should be getting into new areas where the classical approaches really do not work.

DeGroot: I think many statistical techniques have become standard simply because they were easy to apply, just the reason you are talking about, regardless of whether they were always relevant.

Rao: They all arose from applications in biology, but now that stage is past. I don't think we are very successful with statistical methods in psychology or even in economics. Possibly what is wrong with the economists is that they are not trying to refine their measurements or trying to measure new variables which cause economic changes. That is far more important than dabbling with whatever data are available and trying to make predictions based on them. So there's a lot of work that needs to be done in the soft sciences such as psychology and economics.

DeGroot: What does the future hold for C. R. Rao? You mentioned the possibility of traveling in third world countries.

Rao: Well, I will try to continue research to the extent possible with the facilities available wherever I am. And I like teaching and talking to students, trying to inspire them, giving them new problems—so probably I'll continue to do that. And if the Third World Academy forces me to go out and give lectures, I guess I could do that. But I do not know. I would like to continue the type of work I have been doing before, but probably at a slower pace than before.

DeGroot: I'm sure that in whatever you do, you will be as highly successful as you always have been. Thank you, C. R.