Jayanta Kumar Ghosh (1937–2018)

Jayanta Kumar Ghosh, just JKG, to most of his friends was born on 22 May 1937 at Calcutta to Ambernath and Shanti Ghosh. His early years were mostly spent in and around Calcutta. He recalled, happy times spent at a large house with many cousins somewhere in the southern fringes of the city. He had fond memories of early school years at Hartley school in Bhowanipur. After his high school, he joined Calcutta University where much of his academic life took shape. He obtained B A degree in 1956 and M A in 1958 from the university. R. N. Bhattacharya, the eminent probabilist – a classmate and a friend from those days recalls 'Even as a teenager Jayanta was a little shy and reserved. My special relationship with Jayanta was that among all our classmates and contemporaries, I was probably the only one who felt free to talk to him as a friend on various subjects outside of statistics or mathematics. Our other classmates seemed to be somewhat in awe of Jayanta's intellect. We were both voracious readers of all kinds of literature – fiction and non-fiction. Every once in a while I would get some suggestions about a good book he had read (borrowed from the British Council Library in Kolkata). Even during our college days I would be impressed by his broad scholarship.'

He continued his pursuit of doctoral degree under H. K. Nandi and obtained his D Phil in 1964. This was the beginning of his illustrious career of scholarship and service. JKG greatly admired Nandi.

Part of his thesis resulted in a fundamental paper with Hall and Wijsman. The paper lists the authors as 'Hall, Wijsman and Ghosh'. The second part of the two-part paper was written by JKG and this accounts for the curious non alphabetic listing. This was soon followed by an invitation from Wijsman to visit University of Illinois at Urbana-Champaign. JKG had great respect and admiration for Wijsman and kept in touch with him till Wijsman's death. During his stay at Illinois, he spent many hours at the library and worked very hard, learning a wide range of mathematics. D. Basu visited UIUC and persuaded JKG to return to India. Perhaps, the persuasion was not necessary because JKG used to say that the places and people he loves are in Calcutta. In 1966, he returned to Calcutta and joined the Indian Statistical Institute.

In the 1970s with C. R. Rao at the Delhi centre of the ISI, JKG was the leading figure in mathematical statistics at Calcutta. After his early doctoral work in sequential analysis, he moved to asymptotic theory with a deep study of second order efficiency of estimates,

Bahadur efficiency of tests and quantile representation. In 1978 he made, jointly with Rabi Bhattacharya, fundamental contribution to the validity of Edgeworth expansions settling an old conjecture of Wallace. Beyond asymptotic theory, he made fundamental contributions to many other areas of statistics including foundations of sample surveys, sufficiency and invariance and characterization problems.

JKG directly and indirectly supervised a large number of students in diverse fields like set theory, ergodic theory, admissibility, probabilistic number theory. Typically, he would work closely with the student, especially when it was related to his current interests. There were cases, when a student would express intention or desire to pursue a specific topic or problem that he felt was unwise. In such cases he would advise the students, explain why he felt it was not good to work on it but close it by saying 'I have told you what I think is right but the decision is yours. Whatever you decide I will do my best to help.'

Although he was primarily a mathematical statistician, he had wide interests and had solid understanding of many branches of mathematics. Along with his theoretical inclinations, he also developed interest in applications. He was very much interested in applied work and analysis of data. He studied with Supriya Sengupta and B. S. Mazumder on aspects of sedimentation and size distribution of suspended particles. He was very proud of the flume project he set up at the ISI where experiments were conducted and data collected. His interests also led him to collaborate on applications in epidemiology, biostatistics and later in bioinformatics.

In the seventies, the ISI journal *Sankhya* was at a low point. Due to various prevailing circumstances, the publication had become irregular. He tirelessly worked to uplift *Sankhya*, often publishing his own papers in it and encouraging his colleagues to publish their research in it.

In his early days in ISI, he was reserved and not much given to lecturing in his classes. Yet, he was much sought after as a teacher. His classes had a certain originality in them as he attempted to prove, or sometime come up in class with a different proof of a result. He would include current material in the course and would sometime give, as yet unsolved, problems as home work with the hope that it would encourage students to think. He instituted major changes in the curriculum to bring it up to date.

While not directly involved with administration, he was part of many of the major committees that set the policy, set the budget and those that worked with the government. Thus he was familiar with the way the institute functioned. In 1987 he became the Director of ISI. He served successfully in that role. Among other things he played a major role in developing the centre at Bangalore. Even as he dealt with the onerous responsibilities of directorship, he continued his research, supervising students and teaching.

JKG was always interested in the foundations of statistical inference. While most of his work till the 80s was in the frequentist mold, he was also sympathetic to the Bayesian view. His discussions with D. Basu and deep study of his writings eventually convinced him of the Bayesian viewpoint and he became a full edged Bayesian. After his retirement

from ISI, JKG divided his time between ISI and Purdue University and interaction with Jim Berger further reinforced his conviction. His attention now turned to Bayesian inference where he made fundamental contributions to probability matching and reference priors, model selection and Bayesian nonparametrics.

JKG was Fellow of several societies including: Indian National Science Academy; Indian Academy of Sciences; Institute of Mathematical Statistics; Institute of Statistical Mathematics. He was President of the Statistical Section of the Indian Science Congress (1991); President of the International Statistical Institute (1993). He was recipient of several awards, including: Shanti Swarup Bhatnagar Prize of the CSIR, India (1981), Mahalanobis Gold Medal of the Indian Science Congress (1998), P.V. Sukhatme Prize of the Government of India (2000), Honorary D.Sc. by the B. C. Roy Agricultural University in West Bengal, India (2006), the Lifetime Achievement award of the International Indian Statistical Association (2010), Honorary D Sc by the Indian Statistical Institute (2012), *Padma Shri* from the Government of India (2014).

The first thing that struck you when you met JKG, was his gentleness. He was gentle in demeanour, gentle in conversation and gentle in conduct. Being considerate came naturally to him. His office door was always open. You could anytime walk in and talk of whatever was in your mind, academic or otherwise. He would set aside whatever he was doing, listen and help, if needed. In matters academic, he had a knack of converting our vague, half-baked thoughts to meaningful questions. He would freely share his ideas and did not expect or think of seeking credit or joint authorship.

He was fond of literature and had read widely in Bengali and in English. He was familiar with most of the classics. Books were a major component in his life. He read widely; in history, literature and general fiction. He absorbed them, remembered them and would at times, succinctly describe a situation with a quote from Proust or Mark Twain or Tagore. He liked good detective stories but not those that were violent. Later in his life, he found childrens' books more cheerful and preferred reading them.

JKG had a sense of humour. After he visited Japan, some one in the Tea club asked him if he could read Japanese. He promptly answered, 'Yes'; adding a little later, 'if it is written in English'.

He had great love for the city of Kolkata. Whenever he returned from Kolkata, he would start talking of his next visit. Towards the end, he wanted to go back to his city. Unfortunately, the circumstances of his illness did not allow him to do that.

Another major part of his life was ISI. During the final stages of his life, he would often talk of ISI, C. R. Rao, the summer school in Visakhapatnam in the late sixties and the good old days. He found that one of his old theorems with D. Basu was rediscovered and wrote:

> '(He) found Basu and I had proved it in *our* 1969 paper in the *Annals*, that's forty years ago. It brings back to me more than even the memory of the pleasure of joint work the pleasure of friendship so common in old days in Stat Math. I also remembered that when I told Basu of this result, (he) told every one in the dingy tea club we had, close to where Ratan sits now. This must have been in 1966 soon after I joined ISI.'

This love of ISI was also a weakness, for he could not distance himself from it; and this did result in some unhappy moments.

He was generally a cheerful person and loved humour. However, in the last couple of years, his illness and a cardiac surgery began to take its toll. His mood turned a bit somber.

No mention of JKG's life would be complete without mentioning his wife Ira. She was the mainstay of his life. She took care of his needs, his social obligations and helped him to be what he was. They had many friends, many visitors and as a host she excelled in graciousness. She loved reading and gardening. Her presence became essentially indispensable towards the last months of JKG life. Unfortunately, she herself was hit with serious illness and passed away just two weeks before him.

JKG was a humanist who believed in rational thought, while also conscious of its limitations. He admired Buddhism and valued compassion. He lived a life that truly reflected these beliefs. He did not hesitate to bend rules if compassion dictated it.

To quote him from a letter:

> 'Finally, the first things last, as in life. As one gets old and the once solid foundations of one's life begin to disintegrate, a warm friendship matters more than anything else.'

The warm friendships, they had in plenty. They enriched the life of all those who came in contact with them.

JKG's first research interest, part of his doctoral thesis, was in the area of sequential analysis. In his thesis, he studied optimality properties of the Sequential Probability Ratio Test, introduced by Abraham Wald. Sequential analysis considers statistical procedures when the sample size is not fixed in advance but at each stage a decision is made to reject, accept a hypothesis or to continue sampling. The prevailing methods naturally led him to investigate the role of invariance and sufficiency in the reduction of data. In the presence of a group of transformations of the sample that leaves the problem invariant, it is natural to restrict attention to invariant rules. A statistic, i.e. a function $T(X)$ of the sample is said to be sufficient if the conditional distribution of X given T does not depend on the unknown parameter. JKG and independently Hall and Wijsman investigated and clarified the role of the order in which these reduction principles are applied. This resulted in a much cited fundamental paper.

JKG moved away from sequential analysis but did return to the topic a couple of times later. He was fascinated by sufficiency and its measure theoretic intricacies and with his student K. K. Roy characterized models admitting sufficient statistics with non-constant carrier. Later with H. Morimoto and S. Yamada, he proved a very general factorizaton theorem for sufficient statistics in undominated models. Together with D. Basu, in a fundamental paper, he formulated a parametric statistical set-up and studied sufficiency for sample survey models.

He recognized that, approximations, via asymptotics is of major interest and began his long involvement with asymptotic methods. In a well received paper, under mild restrictions, he proved a weaker form of Bahadur's quantile representation. This weaker form is adequate for many statistical applications. The representation approximates the sample quantile with a sum of independent, identically distributed random variables.

In 1978, in a landmark paper, JKG and R. N. Bhattacharya proved the validity of Edgeworth expansion for smooth functions in the context of independent random variables, thus settling a conjecture of Wallace. Edgeworth expansions are refinement of the central limit theorem and provide sharper approximation. To paraphrase from the IMS obituary written by Anirban Dasgupta.

'Professor Ghosh's most cited work is his 1978 joint paper with Rabi Bhattacharya on the validity of Edgeworth expansions for smooth functionals in the iid or independent situations. The work is widely regarded as a masterpiece in controlling the error in the central limit theorem'.

He along with his students, later expanded the work to more general cases.

Another major area of research is the study of higher order efficiency. The popular maximum likelihood estimates are known to be first-order efficient. However there are other estimators that too have this property. Higher order efficiency provides a way to discriminate between first-order efficient estimators. JKG and his students and collaborators made a thorough study of second and higher order efficiency and of Bahadur efficiency in the context of testing of hypotheses. Much of this work constituted his NSF-CBMS lectures and summarized in a monograph.

JKG then moved on to the study of a series of problems among others, the perplexing Neyman Scott models where the parameters increase with the number of observations, Bartlett correction in the frequentist and Bayesian set-up.

Most of his research till the mid eighties falls within the frequentist framework. 'Frequentist' approach is based on interpretation of probability of an event as the limit as $n \to \infty$ of proportion of occurrences of the event in n independent trials. The other, the Bayesian approach starts with the interpretation of probability as the measure of belief in occurrence of the event. JKG started as a frequentist. His interest in foundations and philosophy of inference, along with D. Basu's influence eventually converted him to the Bayesian philosophy.

The basic unknown in statistical models is the value of a parameter θ. Information on θ is obtained by observing a random quantity X whose distribution P_θ depends on θ. In the Bayesian approach, one starts with a probability distribution $\pi(\theta)$ – the prior distribution – for θ and then if $X = x$ is observed, then the prior is updated to $\pi(\theta \mid x)$ the conditional distribution of θ given x, the updating mechanism being Bayes theorem.

In the last two decades of his life, JKG and his collaborators made major contributions to Bayesian inference. The prior in the Bayesian model is a subjective input encapsulating the experimenter's knowledge and belief regarding the parameter. JKG studied and popularized 'probability matching priors'. These are priors which, up to a first order approximation, yield Bayesian inference close to its frequentist analog. He did not advocate use of these priors but viewed them as a kind of standard with which the input of the experimenter's prior can be compared. This led him to investigate reference priors introduced by Bernardo, especially in the multiparameter setup.

Another important area of his study was model selection. As an example, consider the model where the observations Y_i are modelled as

$$Y_i = \sum_1^k \beta_i x_i + \varepsilon_i, \qquad i = 1, 2, \ldots, n,$$

where β_i, $i = 1, 2, \ldots, k$ are the unknown parameters, x_i, $i = 1, 2, \ldots, k$ are fixed covariates chosen by the experimenter and ε_i, $i = 1, 2, \ldots, k$ are random noise, usually modelled as normal random variables. In this situation, each k, gives rise to a model. As k increases, one gets, in term of empirical error, better and better fit of the data, leading to overfitting. The issue is to arrive at an appropriate k. The popular criteria for these are the Bayes Information Criterion (BIC) and the Akaike Information Criterion (AIC). They lose some of their consistency properties in the high dimensional case, where the number of parameters significantly exceeds the number of observations. JKG showed that with an appropriate correction term these criteria are useful in the high dimensional models.

A third major area of interest to JKG was Bayesian non-parametrics where the parameters are infinite dimensional. Consistency of the posterior captures the idea that with large data, the effect of the prior gets washed away.

In addition, JKG and his students proved consistency in mixtured models of an algorithm due to M. Newton and showed its connection to stochastic approximation. This algorithm showed good properties in simulations but a proof of consistency was missing.

Much of his work in Bayesian inference is summarized in two books, one on Bayesian nonparametrics and the other on Bayesian statistics. He along with coauthors from ISI had nearly completed a manuscript on Model selection. JKG used to say that to write a book 'either one should have something new to say or have a new way of saying what is known'. His books well exemplify this principle.

While these are the main lines of his research, he had worked on many other areas including sample surveys, characterization problems, etc. In ISI he had, together with Supriya Sengupta arranged for a flume to be built and studied models for sediment transport. He was also involved in projects related to biostatistics and health. Later in Purdue, he worked on applicable methodology for problems in bioinformatics.

A more detailed account of his research is available in the essay by Clarke and Ghosal in the monograph *Pushing the Limits of Contemporary Statistics*.

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