BIOGRAPHICAL MEMOIRS

Leo A. Goodman

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A Biographical Memoir by
Robert M. Hauser and Michael Hout

Throughout his exceptionally long career, Leo A. Goodman made signal contributions to mathematical statistics, demographic analysis, statistical modeling, and the application of powerful new statistical methods to social data. Goodman's methodological contributions have been cited, adopted, and applied widely. Despite its important theoretical content, almost every contribution is enhanced by novel analyses of significant empirical data, often analyzed previously by other researchers who either made mistakes or made up *ad hoc* procedures. This body of work made Goodman the bridge between statistics and the social sciences, especially sociology and demography. Before Goodman, sociologists who used statistics tended to analyze categorical data as if it were numerical. Goodman, alone and with collaborators listed below, focused on the special properties of categorical data and, over decades, developed the tools social scientists need to make valid inferences from categorical data. Goodman's writing is precise, dense, and repetitive, especially in papers directed to a sociological audience. All the same, his work always rewards a close reading. Through both his writings and personal contact, Goodman has inspired others to undertake innovative and important research.

Leo A. Goodman was born in Brooklyn, New York, on August 7, 1928, to Abraham and Mollie Goodman, Ukrainian Jewish immigrants. He graduated from Stuyvesant High School in 1944 and then entered Syracuse University, where he first developed the dual interests—statistical and sociological—that would characterize his life's work. As an undergraduate student at Syracuse, he majored in both mathematics and sociology, graduating *summa cum laude* in 1948. While trying to decide whether to pursue a doctorate in mathematics at Princeton University or one in sociology at the University of Chicago, an incidental meeting at Princeton with the great statistician Samuel Wilks led him to the former choice. At Princeton, statistical science was then lodged in the Department of Mathematics, and Goodman worked with John Tukey as well as Wilks. He completed his Ph.D. in 1950 and was hired as an assistant professor, shortly after his 22nd birthday, in both the departments of statistics and sociology at the University of Chicago.

Goodman's work often began with the presentation of a problem that others had failed to solve. For example, his first publication, written during the initial year of his doctoral study, was the product of a query on a postcard from W. Allen Wallis to John Tukey. Goodman's introduction to his paper "On the Estimation of the Number of Classes in a Population" is characteristic of his direct and definitive writing style:[1]

> Suppose a population of known size N is subdivided into an unknown number of mutually exclusive classes. It is assumed that the class in which an element is contained may be determined, but that the classes are not ordered. Let us draw a random sample of n elements without replacement from the population. The problem is to estimate the total number K of classes which subdivide the population on the basis of the sample results and our knowledge of the population size. There is exactly one real valued statistic S which is an unbiased estimate of K when the sample size n is not less than the maximum number q of elements contained in any class.

Goodman investigated estimation of the total number of items from a random sample of their (presumably sequential) serial numbers. Here is what prompted the work: "Early in 1943 the Economic Warfare Division of the American Embassy in London started to analyze markings and serial numbers obtained from captured German equipment in order to obtain estimates of German war production and capacity. … This method of analysis was a valuable source of economic intelligence."[2]

Following up earlier work by Richard Ruggles and Henry Brodie,[3] Goodman introduced minimum variance unbiased estimators of the total number of items, whether or not the first number in the series was known, along with an estimator of the variance in that estimator and methods for statistical inference using those estimators. In that same year, Goodman and Harry Markowitz challenged Kenneth Arrow's highly influential finding that no voting system could have all of five properties that might be reasonably be demanded of them.[4,5] They showed that one of Arrow's requirements—essentially that all individual differences in preferences were equal—was questionable and that, when modified, many voting systems were acceptable.

Goodman reported that he and William Kruskal each joined the faculty of the University of Chicago at the outset of the 1950–51 academic year.[6] They discovered, during a conversation at a New Year's Eve party, that each had independently been asked to consult about measures of association in cross-classified data. They decided to work together on this topic, and their joint efforts yielded new measures and four classic papers published over the span of almost twenty years.[7,8,9,10] This work created a minor industry in the statistics of cross-classified data, and the first paper in the series has now been cited almost 4,000 times.

Their approach was to build an analogue to the standard measure of association between a quantitative outcome and a list of predictors, usually denoted R^2. R^2 was commonly interpreted as the proportional reduction of prediction error achieved by using the predictors compared to the errors from predicting that every case would have an average outcome. Goodman and Kruskal derived proportional reduction in prediction error measures for unordered and ordered categories.

In another highly cited paper, T. W. Anderson and Goodman derived useful statistics about the transition probabilities in Markov chains of any order, provided there were repeated observations of the chain.[11] Although the paper is largely theoretical, it was motivated by the observation of preference changes in a panel study of voting. Anderson and Goodman derived likelihood ratio tests and chi-square tests for the constancy of probabilities across transitions, the size of those probabilities, and the order of the chain.

W. S. Robinson's 1950 paper, "Ecological Correlations and the Behavior of Individuals," famously argued that ecological correlations, that is, correlations between the characteristics of aggregates of individuals, could frequently mislead investigators about the corresponding correlations between individual characteristics.[12] Goodman demonstrated that, under certain conditions, individual correlations could be estimated from aggregate data, and that these estimates could be obtained whether the individual correlations were "between two dichotomous variables, between two qualitative variables where one of them is dichotomous, and between two quantitative variables."[13]

In the early 1960s, Goodman's contributions were largely theoretical, with titles including: "On the exact variance of products," "Some nonparametric tests for comovements between time series," and "The variance of the product of K random variables."[14,15,16]

One article about movement over time between one category and another proved to be particularly fruitful, not just for Goodman but for many social scientists. Isadore Blumen, Marvin Kogan, and Philip J. McCarthy proposed a mover-stayer model to account for mobility between industries in a large sample of workers.[17] In the model, there were two types of individuals: those who would never move from an initial category and those whose movements from one period to the next followed a zero-order Markov chain model with constant probabilities. Goodman demonstrated that the estimators offered by Blumen et al. were not statistically consistent and over-estimated the share of stayers, and he developed consistent estimators, methods of estimation, and statistical tests. "Statistical Methods for the Mover-Stayer

Model" was the first article in which Goodman proposed methods for the analysis of square tables in which the diagonal elements (immobility) were treated differently than the off-diagonal elements.[18] In a closing remark, he suggested that application of the improved mover-stayer methods "… could also be used to study occupational and social mobility," thus anticipating his later contributions to the analysis of social mobility tables. Although the reference list included David Glass's classic monograph on social mobility in Great Britain, it was not actually cited in the text.[19]

Goodman offered new methods for the analysis of transaction flows, an instance of data in square cross-classification tables in which the diagonal cells—corresponding to internal transactions—were intrinsically empty.[20] This may have led him to novel analyses of social mobility tables, that is, frequency tabulations of the frequencies of movement (or non-movement) between occupational categories of fathers and sons. Sociologists had long taken "perfect mobility" (statistical independence between the locations of fathers and sons) as the baseline hypothesis from which to investigate mobility from father to son, such as in the influential work of Natalie Rogoff.[21] Partly motivated by Harrison White's work,[22] Goodman introduced the concept of quasi-perfect mobility, that is, statistical independence between origins and destinations, once occupational inheritance, that is, entries on the main diagonal of a mobility matrix, was ignored.[23] He found that the model of quasi-perfect mobility closely fitted mobility tables from Great Britain and Denmark. Importantly, he also showed how to decompose the interactions among groups of cells in the mobility table that contributed to overall fit (or lack of fit) in the models of perfect mobility and quasi-perfect mobility. Goodman returned to this theme by showing how to decide whether to combine categories in a cross-classification table.[24]

In his R. A. Fisher Memorial Lecture, Goodman extended the concept of quasi-independence to the analysis of separable sub-tables of a cross-tabulation with intrinsically missing entries, to specific interactions among cell entries within larger cross-tabulations, and to triangular tables of cells or blocks of cells.[25] In order to estimate frequencies expected under some of the models he proposed, Goodman developed an iterative technique that proved to be a forerunner of the EM algorithm. In a pair of didactic papers, Goodman provided a detailed guide to the analysis of (square) social mobility classifications, focusing specifically on models of quasi-independence in which the main diagonal cells were ignored, but parameters for the entries in the diagonal cells could be estimated from the models.[26,27] Goodman also created an extended catalog of twenty-three quasi-independence models for square cross-classifications with ordered, identical row, and column categories.[28] In addition to the model with parameters for entries on the main diagonals, these models included parameters for upward or downward moves, off-diagonal entries, and crossing of specific boundaries, which he explored in a later paper.[29]

This body of work on tables of categorical variables amounted to an analysis of variance (ANOVA) for counts (more precisely it was an analysis of deviance between the observed and expected counts). It allowed researchers to partition the likelihood ratio for the complete set of counts into main effects, two-way interactions, and higher-order interactions, just as ANOVA partitioned the total sum of squares.

From 1970 to 1975, Goodman also worked on methods for the analysis of cross-classifications of higher dimensions.[30] These included the analysis of social survey data and the causal analysis of panel data.[31,32] In yet another application of the quasi-independence concept, Goodman solved the problem of assessing the fit of Guttman scales, which had eluded researchers for a quarter of a century.[33,34] In the case of a one-dimensional scale, fit could be tested by ignoring all cases that were consistent with the scaling model and testing for independence among items in a cross-classification of item responses in the non-scalable cases.

In the late 1970s, Goodman's attention turned to the specification and estimation of linear scaling models, for which he coined the term "association models" for the analysis of cross-classified data with ordered categories. In a highly influential paper extending the work of Otis Dudley Duncan,[35] who had shown that the linear terms in Simon's "row effects" model[36] could be constrained in a way that would yield a single "uniform association," Goodman introduced an array of nested models for ordered categories.[37] Goodman's models even included the prospect of estimating scores for each of the categories (subject to identifying constraints) that proved particularly useful in applications. Clifford C. Clogg and Goodman extended these models to comparisons of multiple classifications.[38] Goodman compared association models with row and column effects with the canonical correlation model, applied to discrete data.[39] In general, the association models yield correct measures of model fit, whereas the canonical correlation model does not. But if the cross-classification is a discrete version of a bivariate normal distribution or of some other distribution that can be transformed into a bivariate normal distribution, then the association model and the canonical correlation model yield similar row and column scores and model fit.

In the Rietz Memorial Lecture and a paper in the *International Statistical Review*,[40,41] Goodman extended the comparative analysis of association models to correspondence analysis[42] and also developed models for the analysis of square tables with symmetric entries or interactions. Goodman provided a general model for the analysis of cross-classified data, including association models, canonical correlation, and correspondence analysis and showed their relationships with the earlier contributions of Karl Pearson, G. Udny Yule, and Ronald A. Fisher, among others.[43]

Over many years, and doubtless inspired by the work of his friend, Paul Lazarsfeld,[44,45] Goodman addressed methodological issues in latent class analysis. Goodman developed exploratory methods for latent class analysis, and with his student, Clifford Clogg extended those methods to tables of higher dimensions.[46,47] Much later, in 2007, Goodman showed how to assign individuals to latent classes.[48]

In later years, Goodman's works were highly varied. Goodman addressed the analysis of total score and Rasch models in multiple classifications.[49] In a series of papers, Goodman and Michael Hout offered methods for the analysis of cross-classified data that used graphical displays.[50,51,52] Goodman also offered a new way to look at the difference between the arithmetic mean and the geometric mean and the difference between slopes in regressions of raw numbers and their logarithms.[53]

Leo A. Goodman made exceptional contributions to sociology and to statistical methods and models over a scientific career that spanned nearly seventy years. About Goodman's work, Otis Dudley Duncan wrote,[54]

> It is characteristic of Goodman's … work, then, that it solves problems…. Moreover, it solves problems that are important…. Finally, it solves problems in a definitive … way…. The solutions actually supersede and do not merely compete with previous procedures, recipes, and rules of thumb….

Among twenty-eight notable contributions to categorical data analysis that Alan Agresti cites in his 2013 book,[55] four are by Goodman, with no other author being cited more than once.[56,57,58,59] Goodman was also most generous in acknowledging the work of scholars and researchers for whom he had great admiration. These included William Kruskal,[60] Otis Dudley Duncan,[61,62] and Paul F. Lazarsfeld.[63]

In two invited essays, Goodman provided both technical and non-technical introductions to the methods and models that he had pioneered.[64,65] A number of his works are accessible in collections, the several papers with William Kruskal on measures of association for cross classifications,[66] log-linear models and latent structure analysis,[67] and models for ordered categorical data.[68]

Leo A. Goodman was modest, generous, and unflaggingly positive. As remarkably broad as his scientific work was, his friendships spanned an even broader spectrum. Early in his time at Chicago, he became close friends with legal scholar Hans Zeisel and sculptor and ceramicist Eva Zeisel. Other good friends included novelist Saul Bellow and priest-author-sociologist Andrew Greeley. While on sabbatical at Cambridge University, Goodman befriended poet and novelist Sylvia Plath and her husband Ted Hughes. When Goodman relocated to the University of California, Berkeley in 1986, he made many friends in sociology and statistics, of course, but also in English, economics, and the law school.

Goodman had a lot of stories to tell. Mark Becker captured many of them in his interview with Goodman.[69] A less academic one he enjoyed telling was about an evening in the mid-1990s during which the staff at Chez Panisse asked him and anthropologist Shelley Errington to move to another table midway through their meal. Many of us would be affronted. Leo thought "this is going to be special." He said he and Errington would move if they could see the table they were leaving from the table they were being moved to. The maître d' agreed. And, sure enough, special guests soon arrived: Pres. Bill Clinton and First Lady Hillary Clinton.

Throughout his long career, Goodman received many awards, including election to the National Academy of Sciences in 1974 and honorary doctorates from Syracuse University and the University of Michigan. In 1995, he received the American Sociological Association's Award for a Career of Distinguished Scholarship, and in 2005, the organization honored him by naming their award for contributions to sociological methods within fifteen years of the Ph.D. the Leo A. Goodman Award. He retired from the University of California, Berkeley in 2017.

Goodman married artist Anne Davidow in 1960. They had two sons, Andy and Tom, in the 1960s and divorced in 1976. Goodman died of a COVID-19 infection on December 22, 2020. He is survived by his two sons, five grandchildren, and his sister.

Note

This text draws heavily, with permission, on Mark Becker's richly anecdotal 2009 interview of Goodman.[70] We also thank Yu Xie, Trond Petersen, and Alan Agresti for helpful comments.

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