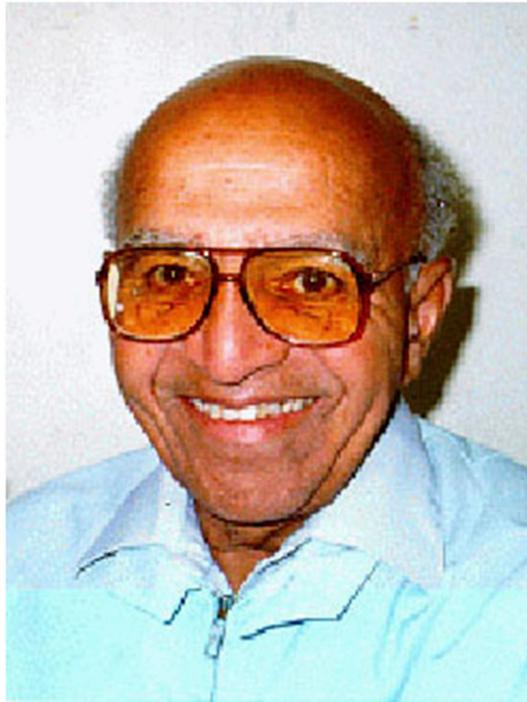


David Blackwell, 1919–2010: An explorer in mathematics and statistics

Peter J. Bickel^{a,1}

David Blackwell, a pioneering explorer who made foundational contributions to several branches of mathematics and statistics, passed away on July 8, 2010. He was born in Centralia, Illinois, on April 24, 1919, and, as his mathematical talents were recognized early, he entered the University of Illinois at Urbana–Champaign at age 16. Although racial discrimination affected his life and career in painful ways, his accomplishments were eventually rewarded with the honors they deserved, including election to the National Academy of Sciences in 1965 as the first Black member and the American Academy of Arts and Sciences in 1968. Nevertheless, his love of mathematics, science, people, and his sunny personality prevailed. Blackwell left contributions that bear his name and other major ideas in five quite different areas of mathematics, statistics, and operations research.

With limited opportunities available to him, Blackwell initially thought of becoming an elementary school teacher. However, his professors at the University of Illinois soon recognized his talent for mathematics and encouraged him to pursue graduate studies in the Illinois Mathematics program instead. During his graduate studies, Blackwell worked with Joseph Doob, one of the founding figures of modern probability theory, a National Academy of Sciences member, and National Medal of Science winner. In 1941, at age 22, he completed a doctoral thesis in the theory of Markov chains, a set of ideas to which he frequently returned in his later work. Following a Rosenwald Fellowship at the Institute for Advanced Studies and various temporary positions, Blackwell obtained one of the few tenure-track academic positions open to him at the time: He joined the Department of Mathematics at Howard University in 1942. In Washington, influenced by M. A. Girshick, he embarked on major research in mathematics and statistics. During the 10 years he spent at Howard, while carrying a heavy teaching load and serving as Department Chair for seven years, Blackwell published 20 papers and a monograph. His contributions from this period ranged over measure theory, renewal theory,



David Blackwell. Image credit: The Blackwell family.

sequential analysis, game theory, and decision theory. They included: what is now known as the Rao-Blackwell theorem, a fundamental improvement scheme in estimation; the foundations of Bayes and minimax sequential analysis (Backward induction) with Kenneth J. Arrow and M. A. Girschick, which also led to later foundational work in dynamic programming (Blackwell policies); clarification of the idea of comparison of statistical experiments, introduced by Bohnenblust, Karlin, and Shapley, through a beautiful theorem that became one of the foundations of statistical decision theory, which forms the basis of modern machine learning; and the Blackwell renewal theorem, a fundamental tool in the analysis of queuing systems.

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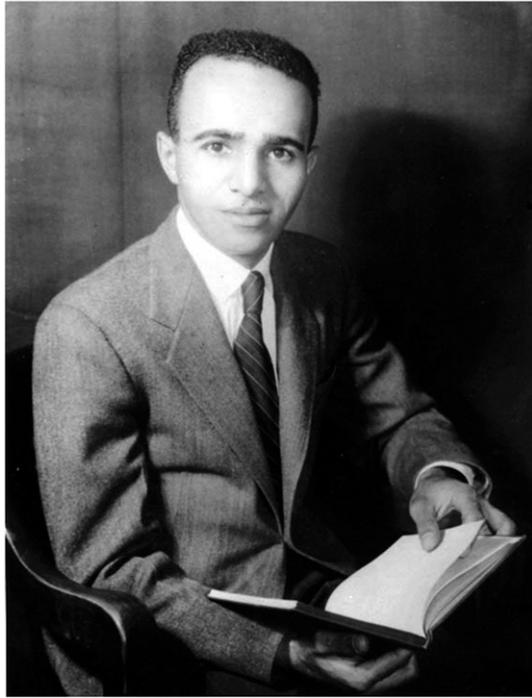
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Blackwell at age 22, the year he received his doctorate and was awarded a prestigious Rosenwald Postdoctoral Fellowship at the Institute for Advanced Study in Princeton, New Jersey. Image credit: The Blackwell family.

Blackwell made further contributions to measure theory, game theory, and statistical decision theory through his monograph (with M. A. Girschick), *Theory of Games and Statistical Decisions* (1).

In 1954, after an initial attempt in 1942, which failed due to the racial prejudice of some faculty families, Blackwell was appointed Professor in the newly formed Department of Statistics at the University of California, Berkeley, which had just split off from the Mathematics Department (2). There, while continuing to contribute to probability theory and statistics, in part collaborating with new colleagues, Blackwell turned his attention more fully to game theory and a new interest, information theory. Working with Leo Breiman and Aram Thomasian, he proved the Shannon transmission theorem for a class of channels, including a novel type, now called the Blackwell channel. He also began to work in dynamic programming, which is now called reinforcement learning. In a series of papers, Blackwell gave a rigorous foundation to the theory of dynamic programming, introducing what have become known as Blackwell optimal policies.

In 1967, Blackwell added yet another area of research, while continuing to contribute to the ones we have cited: the connection between game theory and formal logic. In particular, Blackwell showed how games could be used to define classes of sets studied by logicians. This spawned a small industry in the use of Blackwell games as a tool in pure mathematics. Until his retirement in 1988, Blackwell continued to

make substantial contributions to several of the areas he touched significantly during his life: Probability, mathematical statistics, information theory, game theory, dynamic programming, and set theory.

In an interview with Donald Albers (3), Blackwell gave his views on his explorations: "Basically, I'm not interested in doing research and I never have been. I'm interested in understanding and that's quite a different thing."

Blackwell loved to pass on his understanding and was a marvelous teacher at all levels. Some of his 65 doctoral students, collaborators, and former colleagues, including the author, testified to this in "A tribute to David Blackwell" (4). In my case, a question about a possible generalization of a result in Blackwell and Girschick led to an hour's discussion in which he made clear what was and was not possible. Blackwell then clarified completely how the problem should be treated. The discussion led to a joint paper (5) in the *Annals of Statistics* in 1967 and became the foundation of a collaboration between Colin Mallows and myself in 1988 clarifying a related question.

Blackwell encountered obstacles that he should never have had to face. For example, when he was a Fellow at the Institute for Advanced Studies, Blackwell's thesis advisor, Joseph Doob, had to intervene to ensure him privileges at Princeton University, which were normally granted to fellows of the Institute.

Blackwell did not forget his experiences and, when he could, passionately strove to attract young African Americans to enter the sciences and to help them achieve their goals. Together with Leon Henkin, he developed a program to expose students from historically Black universities and colleges to the mathematical sciences through summer schools. Blackwell also co-organized programs for high school students to come to Berkeley, gave lectures at historically Black universities, and supported African American students in many other ways.

Eventually, Blackwell was honored as he should have been much earlier, with membership and prizes from several societies and 12 honorary doctorates. He was awarded the National Medal of Science, but only



Blackwell (Center) with longtime collaborator Meyer A. ("Abe") Girshick (Right) and friend and colleague Kenneth Arrow (Left) in 1948. Reprinted from ref. 6 with the permission of the Institute of Mathematical Statistics.

posthumously in 2014. The University of California, Berkeley named a new dormitory, Blackwell Hall, after him in 2018. Blackwell's eternal curiosity and search for "understanding," the brilliance and clarity of his thinking, and his exceptional charm and kindness are remembered and missed by all who knew him

well: family, friends, collaborators, colleagues, and students.

Acknowledgments

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- 1 D. A. Blackwell, M. A. Girshick, *Theory of Games and Statistical Decisions* (Wiley, New York, 1954).
 - 2 C. Reid, *Neyman...From Life* (Springer, 1982), pp. 182–183.
 - 3 D. J. Albers, G. L. Alexanderson, *Mathematical People: Profiles and Interviews* (A. K. Peters, Wellesley, MA, 1985).
 - 4 R. Wets *et al*, A tribute to David Blackwell. *Not. Am. Math. Soc.* **58**, 912–928 (2011).
 - 5 P. J. Bickel, D. Blackwell, A note on Bayes estimates. *Ann. Math. Stat.* **38**, 1907–1911 (1967).
 - 6 M. H. de Groot, A conversation with David Blackwell. *Stat. Sci.* **1**, 40–53 (1986).