Harry M. Markowitz

Research scientists tend not to be interdisciplinary—they are trained in a specialty—and if the planets are in the correct alignment, they are able discover or expand knowledge within that specialty. A few researchers, as a result of their training, experiences, and possibly their inherent curiosity, work in many somewhat unrelated fields and produce valuable discoveries that cross disciplines. Harry Markowitz has proved to be in the latter group. He is comfortable at a university expounding in the classroom on financial investments and the theory of constructing a stock portfolio, or discussing with financial managers on how to take modern portfolio theory and apply it to their money-on-the-line real-world of investments. But, he can also discuss his other contributions with researchers and practitioners in linear programming, computer simulation, and Operations Research (OR) modeling. He was the 1989 Operations Research Society of America (ORSA) and the Institute of Management Sciences John von Neumann Theory Prize. In 1990, Harry was a co-recipient of The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel (Nobel Prize in Economics). He has excelled in both the academic and practitioner worlds, and his research has helped to transform Wall Street as much as any other individual in the past 50 years.

From Comic Books to Darwin

Harry Markowitz was born in Chicago on August 24, 1927, the only child of Morris and Mildred Markowitz who owned a small grocery store (Markowitz 1991). Although Harry grew up during the Great Depression, his family lived in a nice apartment and always had enough to eat—Harry even had his own room. He had what many people would consider a normal childhood, playing baseball and touch football in a neighborhood park, plus playing the violin in the high school orchestra. Harry also enjoyed reading, particularly comic books and adventure magazines, including The Shadow. In late grammar school and throughout high school, he enjoyed popular accounts of physics and astronomy. At Carl Schurz High School, Harry began to read original philosophical works, especially those of David Hume and Charles Darwin’s On the Origin of Species. Even at that early age, Harry enjoyed Hume [“my philosopher” (Markowitz 1993, 3] because his views allowed for the development of theories or models; he recognized that empirical testing was possible by building upon Hume’s empirical emphasis (Markowitz 1993). With respect to Darwin, Harry, in his Nobel Prize autobiography, stated that he “was moved by Darwin’s marshalling of facts and careful consideration of possible objections” (Markowitz, 1990).

Having grown up in Chicago, it was assumed that Harry would attend The University of Chicago, like his uncle William Markowitz, the astronomer, known for his standardization of time. Harry did not enter with a scholarship, but later won scholarships and fellowships. In 1945, Harry enrolled in the University of Chicago’s special two-year bachelor’s degree program; he found all the courses of interest as they emphasized the reading of original materials. He was especially interested in the philosophers he read in a course called OII: Observation, Interpretation and Integration (Markowitz 1990).
Becoming an economist was not one of Harry’s childhood dreams. After earning his Bachelor in Philosophy degree in 1947, Harry had to choose an upper division concentration and he decided on economics. As he noted in an interview (Yost 2002, 3), “I liked the applications that economics had; the theoretical structure to the discipline.” Micro-economics and macro-economics were possible choices, but eventually it was the economics of uncertainty which captured his interest. Harry spent much of his time studying the theory of games and expected utility theory of John von Neumann and Oskar Morgenstern, augmented by Jacob Marschak’s arguments concerning expected utility, the Friedman-Savage utility function, and Savage’s defense of personal probability (Markowitz 1990). He had the good fortune to have the latter three—Milton Friedman, Jacob Marschak and Leonard Savage—among his teachers at Chicago in his graduate studies.

Professor Tjalling Koopmans taught a course on activity analysis that emphasized the economic notion of efficiency and the analysis of efficient and inefficient production activities, concepts that proved crucial to Harry’s future research and accomplishments. Koopmans was also director of the Cowles Commission for Research in Economics and invited Harry to become one of its student members. (The Cowles Commission was founded in Colorado Springs in 1932 by Alfred Cowles, a businessman and economist. It is dedicated to the pursuit of linking economic theory to mathematics and statistics. In 1939, the Cowles Commission moved to the University of Chicago. Both Friedman and Koopmans received the Nobel Prize in economics.)

When it was time for choosing a topic for Harry’s dissertation, a chance conversation changed the course of events. As Harry related (Yost 2002, 4):

Now several years later, I am at the stage where I have to choose a dissertation. I am now at a Masters and I am working towards my Ph.D. I went to my advisor, Professor Jacob Marschak, to ask him if he had any suggestions about a dissertation topic. He was busy, so I sat out in his anteroom. There was another gentleman there and we got to talking. He was a broker and suggested that I apply mathematical statistical techniques to the stock market. So when I got in to see Professor Marschak I said, ‘The guy out there suggested I do a dissertation on the stock market.’ At the time I was a student member of the Cowles Commission and Marschak had been formerly the head of the Cowles Commission. Marschak explained that Álfred Cowles, who had endowed the Cowles Commission, was particularly interested in the application of econometric techniques to the stock market. Marschak did not know the financial literature, and he suggested I see Professor Marshall Ketchum in the Business School.

Harry often tells the story of his epiphany, how the basic concepts of portfolio theory came to him one afternoon in the library while reading the 1938 book, Theory of Investment Value, by John Burr Williams (Markowitz 2002, 154). Williams proposed that the value of a stock should equal the present value of its future dividends. Because future dividends are uncertain, Harry
Interpreted Williams’s proposal as an investor should value a stock by its expected future dividends. But if an investor were only interested in expected values of securities, the investor would only be interested in the expected value of the portfolio. And, to maximize the expected value of a portfolio, an investor would need to invest only in a single security. This, Harry knew, was not the way investors did or should act—one does not put all of their eggs in one basket. Investors diversify because they are concerned with risk as well as return. Thus, action based on expected return only (like action based on certainty of the future) must be rejected as descriptive of actual or rational investment behavior. Williams’s seminal text was written shortly after Graham and Dodd’s Security Analysis (1934), and drew heavily from their valuation approach. Moreover, the Graham and Dodd low price-to-earnings and net current asset value (buying stocks for their liquidation or break-up value) strategies were included in the Williams monograph.

To diversify or not to diversify

As Harry noted in his article on the early history of portfolio theory (Markowitz 1999):

“In the Merchant of Venice, Shakespeare has the merchant Antonio say:

My ventures are not in one bottom trusted. 
Nor to one place; nor is my whole estate
Upon the fortune of this present year;
Therefore, my merchandise makes me not sad.
Act I, Scene 1

Clearly, Shakespeare not only knew about diversification but, at an intuitive level, understood covariance.”

To Harry, an obvious measure of risk came to mind, the variance of the portfolio. The fact that portfolio variance depended on covariances of the securities added to the plausibility of the approach. Since there were two criteria, risk and return, it was natural to assume that investors selected from the set of Pareto optimal (nondominated) risk-return combinations. The fact that the variance of the portfolio, that is the variance of a weighted sum, involved all covariance terms reinforced reasonableness of the approach. The riskiness of the portfolio was composed not only of the riskiness of the individual securities, as measured by their standard deviations, but also by the relative movements of the securities to one another, as measured by the covariance or correlation coefficient of the securities.

To minimize risk, one seeks to identify securities with lower, if not negative covariance or correlation coefficient. Since there were two criteria—risk and expected return—the natural approach for an economics student was to imagine the investor selecting a point from the set of Pareto optimal combinations of expected return and variance of return. Harry labeled the combinations of risk and return that were nondominated by other combinations as efficient and named the set of these points the efficient frontier. Over the succeeding years, the Markowitz approach to portfolio analysis has undergone various modifications, but it has always been concerned with finding the maximum return for a given level of risk, or the minimum risk for a given level of return. The efficient frontier traces out the optimal points along the risk-return frontier. For an investor, the choice of a portfolio’s expected return and standard deviation is determined by the investor’s tolerance of risk (Markowitz 1952a, 1956, 1959, 1987). Harry’s efficient frontier was introduced in his “Portfolio Selection” article, which was published in 1952 in The Journal of Finance. Marshall Ketchum, Professor of Finance in The Graduate School of Business at The University of Chicago, the gentleman with Harry talked about the financial

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dissertation topic, was Editor of The Journal from Finance from 1946 to 1955 and served as President of the American Finance Association.

### Harry at RAND

Although Harry had finished his course work but not his dissertation, he felt that it was time to find a job. While attending a meeting of the American Economic Association, he met members of the RAND Corporation’s economics department (RAND being a U.S. Air Force sponsored research organization in Santa Monica, California). They expressed interest in Harry’s research and offered him a job at fifty percent more than an offer he already had from a university—Harry left the University of Chicago for RAND in early 1952 (Yost 2002, 7-8). Harry’s initial RAND research was applying linear programming (LP) to economic problems.

Harry’s first exposure to LP occurred at RAND when he was asked to read George Dantzig’s paper on the simplex method (Dantzig 1951) and to supervise the computer programming and the running of RAND’s first simplex code on an IBM Card Programmed Calculator (CPC). (The CPC consisted of a tabulator [punched-card accounting machine], an electronic calculator, and a bank of 16 mechanical storage registers, all strung together with cables; its input and output was via punched cards.) The LP problem under investigation had 30-40 equations, but the CPC was capable of only doing up to four simplex iterations (steps) per day (Yost 2002, 8). George Dantzig, the developer of linear programming and the simplex method, joined the Rand staff in June of 1952, and over time, with the programming talent of William Orchard-Hays, RAND’s ability to solve LP problems made great advances as computer speeds increased and computer-based LP algorithms improved (Orchard-Hays 1984, Markowitz 2002). Dantzig’s work contributed to the solution of the portfolio selection problem in the following ways (Markowitz 2002, 155):

Markowitz (1956) defines the portfolio selection problem as that of finding mean-variance efficient portfolios subject to linear equality and inequality constraints. This is the same constraint set as that of linear programming, but with mean-variance efficiency rather than the optimization of a linear function as the objective. The portfolio with maximum expected return, when it exists, is the natural starting point in tracing out the set of efficient portfolios. Since expected return is a linear function of portfolio investments, finding the portfolio with maximum expected return is a linear-programming problem. Dantzig's simplex algorithm not only provides the solution to this problem, but also provides the critical line algorithm [for generating the efficient frontier] with various other services. In particular, it determines whether or not the constraint set specified by the analyst is feasible, whether or not feasible portfolio expected return is bounded and, if the model is rank deficient, it provides an equivalent model which is not rank deficient.
The Book: *Portfolio Selection: Efficient Diversification of Investments*

In 1954, Harry received a call from Yale Professor James Tobin inviting him to spend the 1955-1956 academic year at Yale—the Cowles Commission was moving there. Tobin, a Harvard Ph.D. in economics, was also director of the newly named Cowles Foundation for Research in Economics at Yale. Harry earned his Ph.D. in Economics from The University of Chicago in 1954. He invited Harry to write a Cowles Foundation monograph on portfolio theory. The Cowles Commission had been established in the 1930s to research economics and several of its early researchers studied the stock market. The Cowles Commission greatly influenced Economic and Econometric thought, producing a number of Nobel laureates. T.J. Koopmans, the Cowles Commission director, and its former director, Jacob Marschak, invited researchers including many future Nobel Prize winning economists, such as Kenneth Arrow, Gerard Debreu, Lawrence Klein, Tjalling Koopmans, and Franco Modigliani. A draft was finished during Harry’s visit; it was reviewed by Tobin and the economist Gerard Debreu (a Cowles research associate—both Tobin and Debreu would later receive the Nobel Prize in economics), revised by Harry, and published in 1959 under the title *Portfolio Selection: Efficient Diversification of Investments* (Markowitz 1959). The Markowitz gained its place of significance in the literature particularly following the work of his student, William (Bill) Sharpe, published in work on the Capital Asset Pricing Model CAPM, in the 1960s.

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Wolfe’s Generalization

“...My work at the RAND Corporation did not include ‘portfolio analysis.’ But no one objected to my taking the time to write my (Markowitz1952[a]) and (Markowitz1956) articles. I submitted the latter to the *Naval Research Logistics Quarterly (NRLQ)* edited by Alan J. Hoffman. Elsewhere, Phil Wolfe [joint with Marguerite Frank, (Frank and Wolfe 1956)] had been working on the quadratic-programming problem, to minimize a quadratic function (Q – λL, Q positive semidefinite, L linear) subject to linear constraints. Wolfe also submitted his work to *NRLQ*. Hoffman sent Wolfe's paper to me and my paper to Wolfe for refereeing. We both recommended that the other paper be published, and both were [published in the same joint issue of *NRLQ*, 1956, 3(1and2)]. As a by-product of tracing out the efficient frontier, the critical line algorithm minimizes Q - λL (for variance Q and expected return L) for all λ≥ 0. Thus the critical line algorithm is, incidentally, a quadratic programming algorithm. It struck Phil Wolfe that the critical line algorithm solves the quadratic-programming problem in a sequence of steps which are precisely the same as the steps by which the simplex algorithm solves the linear-programming problem, with one exception. The variables of the quadratic program come in pairs 𝑥, 𝜃. When one of these pairs is IN the linear programming ‘basis,’ the other is OUT. Wolfe thus defined quadratic programming as an example of linear complementarity programming. At first it seemed that the practical use of this observation was to easily convert a linear-programming code into a quadratic programming (or portfolio selection) code. Subsequently, it was found that other problems satisfied the linear complementarity format, e.g., non-zero-sum games (Lemke 1965).” (Markowitz 2002, 155)

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*On sharing knowledge*

“One day in 1960, having said what I had to say about portfolio theory in my 1959 book, I was sitting in my office at the RAND Corporation in Santa Monica, California, working on something quite different, when a young man presented himself at my door, introduced himself as Bill Sharpe, and said that he also was..."
Its importance to financial analysts, was readily recognized, but, possibly due to its title, its value did not become apparent to researchers in mathematical programming and the general operations researcher.

The monograph built upon Harry’s 1952a and 1956 papers and their extensions. Brealey (1991) describes four of Harry’s extensions: “First, Markowitz analyzes the utility implications of alternative selection rules and in the case of semi-variance criterion, he discusses the solution procedure. Second, Markowitz includes a discussion of portfolio selection under logarithmic utility and points out that the portfolio that maximizes the geometric mean return is approximately mean-variance efficient. Third, he showed that as the number of securities in the portfolio is increased, portfolio variance approaches the average covariance. Finally, he suggested that the covariance matrix may be simplified if the correlation between security returns result simply from the common influence of the market” (Brealey 1991, 8-9). As Breasley further notes: “He [Harry] is at all times concerned with the problems of practical implementation” (Breasley 1991, 9).

In Appendix A: The Computation of Efficient Sets and in Appendix B: A Simplex Method for Portfolio Selection, Harry clarifies the use of Frank and Wolfe’s (1956) quadratic programming algorithm and the role of his critical line algorithm (Markowitz 1956). Harry notes: “[Frank and] Wolfe was primarily concerned with minimizing a quadratic, and incidentally noted that the amended simplex algorithm would solve the portfolio selection problem; as compared with Markowitz, who was primarily concerned with the portfolio selection problem and incidentally noted that the critical line algorithm would minimize a quadratic” (Markowitz 1959, 222). He further asserts the equivalence of the two algorithms and concludes by stating: “The practical significance of the above result is that any of the linear programming codes for high speed, internally programmed computers can be conveniently converted to a quadratic programming code for solving, among other things, the portfolio selection problem” (Markowitz 1959, 339).

**Return to RAND: Pivoting and Simulation**

On his return to RAND in 1956, Harry continued his earlier work with the economist Alan Manne and extended their previous research to develop industry-wide and multi-industry activity analysis models of industrial capabilities (Markowitz 1990, Manne and Markowitz 1963). The resulting LP model was rather large—had many equations and variables—and the available LP computer codes were restricted to about 200 equations. They looked for ways to modify or reduce the structure to make it computationally tractable. As their model’s equations were such that few variables had non-zero coefficients, they were able to solve small problems by hand by choosing the simplex method’s pivot elements so that the Gaussian elimination of a pivot element introduced as few non-zeros as possible; Harry developed an approach and a pivot selection rule, when applied to a large-scale problem, greatly reduced the generation of the transformed matrix’s nonzero elements (Markowitz 1957). Harry described such systems as

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having sparse matrices, a term and method that has had application to similar computational problems. This idea was carried out at RAND, programmed by Orchard-Hays, within a product form of the inverse LP computer code to solve large models with relatively few non-zero coefficient (Dantzig, Orden and Wolfe 1954, Orchard-Hays 1984, Markowitz 2002). “That was the hardest thing he had to program,” reported Orchard-Hays (Yost 2002, 10).

In the 1950s, RAND was using computer-based simulation procedures to evaluate military situations, with special emphasis on war games. To that end, RAND created a logistics laboratory within its Economics Department. Although Harry was familiar with simulation ideas and techniques as applied to industrial operations and warfare research, his first hands-on exposure to such simulations was when he was assigned to the laboratory to coordinate the development of its computer-based simulation models (Markowitz 2002, Yost 2002). The laboratory’s first simulation model, called LP1, “was a man-machine simulation in which actual air force logistics officers played the role of air force logistics officers. The computer flew simulated missions, generated part failures and other maintenance requirements, and kept track of parts supplies and aircraft status” (Markowitz 2002, 157).

Some time after LP1 was finished, Harry received a job offer from the General Electric (GE) Company and accepted a position with its Manufacturing Services Department located in New York City. Alan Rowe, a former UCLA faculty member and RAND consultant, was now with GE and was the supervisor of the programming of a large, detailed job-shop simulator. Harry, based on Rowe’s experiences and his own understanding of the problems in building a simulator, had developed ideas as to how to reduce programming time and increase a simulator’s flexibility. He applied his ideas to the building of the GE Transformer Department’s shop simulator, the General Electric Manufacturing Simulator (GEMS). Although GEMS was well received at GE, it was not as flexible as Harry hoped it would be.

Harry gave much thought to what attributes a simulation should have and decided to write a non-proprietary simulation language. He did not want to develop it at GE because it would then be proprietary. He went on the job market and returned to RAND to put his ideas to work. At RAND, Harry teamed up with Bernard Hausner and, with the help of Herbert Karr, developed SIMSCRIPT, a very powerful, influential, and long-lived computer-based simulation system (Markowitz, Hausner, and Karr 1963). SIMSCRIPT introduced some novel concepts. It was “designed to facilitate the programming of ‘discrete event’ simulation models, especially ‘asynchronous’ discrete even simulators, as compared to continuous time or difference equation models” (Markowitz 2002; 157). RAND’s SIMSCRIPT program was made available without charge through the SHARE organization, a nonprofit, volunteer-run user group for IBM mainframe computers that was founded in 1955 for exchanging technical information about programming languages, operating systems, database systems, and user experiences.
What is Simscript?: Entities, attributes and sets

“The objective of SIMSCRIPT was to allow the simulation programmer to describe the world to be simulated, and relieve said programmer from implementation details insuffat as we could. The SIMSCRIPT world view is as follows: As of an instant in time the system to be simulated has a status that changes at points in time called events. Status is described in terms of how many of various types of entities exist, what are the values of their attributes, and what entities belong to the sets which other entities own. Early 21st Century programming languages are likely to refer to Entities, Attributes, and Sets as Objects, Properties, and Collections (or Child-Parent relationships). Programming languages at the beginning of the 1960s spoke instead of variables and arrays.

“The SIMSCRIPT [I] programmer described the entities, attributes, and sets of the system to be simulated on a Definition Form. In those days, the computer input was typically the punched card. The data written on the Definition Form, to be keypunched and placed in the SIMSCRIPT source program deck, included names of entity types; names of attributes, their data types, and precision information; the names of sets plus information as to what type of entity owns the set, what type belongs to it, and how the set is organized.

“Changes in status were described in event routines written in the SIMSCRIPT programming language. The language included commands to CREATE and DESTROY entities, FILE entities into or REMOVE them from sets, FIND set members meeting specified tests, DO some action(s) FOR EACH member of sets, CAUSE or CANCEL subsequent event occurrences, etc., as well as perform arithmetic operations on attributes. We sought to make the commands English-like, ‘self-documenting’ (Markowitz 2002, 157).

Once again, Harry left RAND, this time to join with Herb Karr to form the California Analysis Centers, Inc. (CACI) to provide SIMSCRIPT consultant services and courses. They each put up $6,000 as the initial capitalization; CACI was incorporated on July 17, 1962. Harry was chairman of the board and technical director, and Herb was president (Yost 2002). Harry then joined with RAND simulation researchers, Philip Kiviat and Richard Villaneuva, to develop and design a new version of SIMSCRIPT—SIMSCRIPT II—a user-oriented, general-purpose simulation programming language. It was released by RAND in 1969. Under contract to IBM, Harry, based on SIMSCRIPT II, helped to develop an experimental programming language integrated with a database management system, the EAS-E system (Malhotra, Markowitz, and Pazel 1983; Markowitz 2002). EAS-E (pronounced EASY) was built around the entity, attribute, and set (EAS) view of application development. IBM used EAS-E for an internal application, but it was never released as a product. CACI developed and marketed a proprietary version of SIMSCRIPT II, SIMSCRIPT II.5. In 1968, Harry left CACI and, for the first time, joined academia as a professor at the business school of the University of California-Los Angeles (UCLA).

Going public

“By the beginning of 1968 CACI had grown from Herb and me to a small but growing company planning to ‘go public.’ CACI’s initial public offering did in fact take place during the second half of 1968. That was the good news. The bad news was that Herb and I had a major disagreement over the pricing of a new product, then a disagreement over how to settle disagreements. This was finally settled on March 15—the Ides of March—of 1968 when Herb Karr, with about 47% of CACI stock and Jim Berkson, vice president of finance, with about 5% of the stock, fired me with about 47% of the stock.”

(Markowitz 2002, 159)

Epilogue re RAND

Although Harry was probably first hired at RAND based on his University of Chicago research on portfolio analysis, his Rand research activities did not involve such analysis. Harry published four of the seven papers of which he is most proud while at RAND (Markowitz 2009). These

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The Peripatetic Professor cum Consultant

During his academic career, Harry taught M.B.A. and Ph.D. level courses in investments and portfolio management. He was a professor at UCLA (1968-1969), University of Pennsylvania’s Wharton School (1972-1974), and Rutgers University (1980-1982). From 1974 to 1983, he was a staff member at IBM’s T. J. Watson Research Center, Yorktown Heights, New York. In 1982, Harry was appointed the Marvin Speiser Distinguished Professor of Finance and Economics at Baruch College, City University of New York. He was at Baruch College when he was awarded the Operations Research Society of America’s 1989 John von Neumann Theory Prize, and the 1990 Nobel Prize in Economic Sciences (joint with Merton Miller and William Sharpe) for pioneering work in the theory of financial economics. In 1993, he retired from Baruch College as Distinguished Professor Emeritus. He was a visiting Professor at Hebrew University, Jerusalem; University of Tokyo; and the London Business School. Harry moved to San Diego, where he lives with his wife Barbara. He is an adjunct professor at the Rady School of Management, University of California, San Diego. Harry and Barbara support the nonprofit Rational Decision Making Research Institute, where he developed a new non-proprietary version of EAS-E (Yost 2002, 33-34; EAS-E.ORG 2009 [Web site]).

Harry continued to consult during his academic tenure, serving, from 1984, as President of the Harry Markowitz Company, and, from 1990-2000, as Director of Research, Global Portfolio Research Department (GPRD), for the Daiwa Securities Trust Company, the U.S. affiliate of Japan’s Daiwa Securities. GPRD develops research models and manages money for institutional clients using the Daiwa (Markowitz) portfolio mean-variance optimization system (Bloch et al. 1993). Harry created the GPRD as a start-up research department, and allowed researchers considerable flexibility in terms of suggesting models to be tested; however, Harry insisted on using academically-rigorous standards in a Wall Street atmosphere. The GRPD published several journal articles in addition to managing institutional assets. In the early 2000s, Harry worked in joint research with Bruce Jacobs and Ken Levy of Jacobs and Levy Equity Management, a provider of quantitative equity strategies for institutional clients, where he helped to construct the JLM Market Simulator (Jacobs, Levy, and Markowitz 2004). The JLM Sim is an asynchronous simulation that investors can use to create a model of the market using their own inputs. The investor’s portfolio selection choice comes from the risk-aversion coefficient parameter which helps the client choose from a desired portfolio on the efficient frontier.

Harry has made great intellectual contributions to the worlds of finance, investment management, linear programming, sparse matrices, and computer simulation, many of which are discussed in his collected papers (Markowitz 2008). He has been a successful endowed professor, consultant, and research staff member. Modern portfolio theory is now a standard topic in college courses and texts on investments, and widely used by institutional investors and by many quantitative money managers for stock selection for equity portfolios.

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In 1990 was the joint recipient (with Merton Miller and William Sharpe) of the Nobel Prize in Economics for his for pioneering work in the theory of financial economics.


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**Acronyms**

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<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>CACI</td>
<td>California Analysis Centers, Inc</td>
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<tr>
<td>EAS-E</td>
<td>EASY; EAS stands for entity, attribute, and set</td>
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<td>GE</td>
<td>General Electric (GE)</td>
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<tr>
<td>GEMS</td>
<td>General Electric Manufacturing Simulator</td>
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<td>GPRD</td>
<td>Global Portfolio Research Department</td>
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<td>LP</td>
<td>Linear Programming/Linear Program</td>
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<td>NRLQ</td>
<td><em>Naval Research Logistics Quarterly</em></td>
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<tr>
<td>ORSA</td>
<td>Operations Research Society of America</td>
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