Louis Auslander (1928–1997)

S. S. Chern; Thomas Kailath; Bertram Kostant; Calvin C. Moore, Coordinator; and Anna Tsao

Louis Auslander died on February 25, 1997, from complications following a cerebral hemorrhage. He was sixty-eight. Born July 12, 1928, in Brooklyn, New York, he received his Ph.D. under S. S. Chern at the University of Chicago in 1954. He held faculty positions at Yale University, Indiana University, Purdue University, University of California at Berkeley, and Yeshiva University before joining the faculty at the City University Graduate Center in 1965. Since 1971 he had been Distinguished Professor of Mathematics and Computer Science at CUNY Graduate Center, receiving the President's Medal there in 1989. He was a Guggenheim Fellow in 1971–72 and was a member of the Institute for Advanced Study in Princeton for the years 1955–56, 1956–57, and 1971–72. He was also a frequent consultant at the U.S. Naval Research Laboratory and for IBM, AT&T, and Hughes Laboratories during his career, and for two years, 1989–91, he served as program manager for the Applied and Computational Mathematics Program at DARPA (Defense Advanced Research Projects Agency).

Equally at home in pure and applied mathematics, Lou was an insightful mathematician with wide-ranging interests who made contributions to many different areas. Over the years he worked in Finsler geometry, in the geometry of locally affine and locally Euclidean spaces, in the theory of solvmanifolds and nilmanifolds, on the representation theory of solvable Lie groups, on many aspects of harmonic analysis (both in continuous and discrete situations), on development of new fast algorithms for discrete Fourier transforms, and on the design of signal sets for communications and radar, among other areas. He was the author of over one hundred papers and ten books, and he supervised the dissertations of eighteen doctoral students (see the accompanying box.)

He was an unusually effective advocate for the development of applications of mathematics, and in his two years of government service as a DARPA program manager he was very effective in shaping and enhancing funding for applied mathematics programs. Indeed, he aggressively sought out opportunities for mathematics and mathematicians and in an active manner defined, shaped, and encouraged research areas and connections. His successes at DARPA were driven by his scientific insights, his vision, and his political astuteness (all of which he had in abundance).

Following are reflections by five people who worked closely with Lou at different times in his career.

—Calvin C. Moore, Coordinator

S. S. Chern

I joined the University of Chicago in the summer of 1949, and Louis was one of my first students. An interesting thing happened: Chicago was a large department and offered many mathematical topics of choice, and he chose Finsler geometry. I had just written a paper on the subject and had suggested he write what might be called the first paper on global Finsler geometry [1]. He was a courageous man. His thesis is now of historical significance in Finsler geometry. I recently came into contact with the subject again. I have great difficulty in talking to people about a great landscape; Louis was unique.

Louis was a talented and devoted mathematician. His later works are in the areas of functional

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analysis, and I leave it to others to comment on this. We maintained a continuous social and mathematical contact, and I always enjoyed talking to him. He never lost interest in mathematics, and we were generally in agreement.

Calvin C. Moore

I first met Lou in the fall of 1963 when he came to Berkeley as a visiting professor for the 1963–64 academic year. Lou was by then an established mathematician, and I was a newly appointed and rather junior assistant professor. Lou was full of ideas, and we started to talk. The results of Kirillov describing the dual space of a connected and simply connected nilpotent Lie group had recently burst upon the mathematical scene and were being absorbed. Lou suggested that we work on the case of solvable groups. Lou brought with him a profound knowledge and intuitive feeling for solvable Lie groups from his previous work in differential geometry, especially work on locally affine and locally Euclidean spaces. Lou was just learning unitary representation theory, in which I had some background, so we were well matched, and the collaboration was extremely fruitful and exciting. Lou taught me a lot about doing mathematics and about the process of collaborating with others, which was especially important to me. This was the first joint work that I had undertaken. I am forever in his debt for all the things mathematical and otherwise that I learned from him during this year. We ended up publishing a lengthy jointly authored AMS Memoir [3] on our work. We made good progress on the problem but did not solve it, and it was a few years later that Lou and Bert Kostant made the real breakthrough and obtained a result for solvable Lie groups fully as elegant, complete, and penetrating as the Kirillov result. During his stay in Berkeley Lou also attracted a Berkeley graduate student, Jon Brezin, to work with him. Jon followed Lou to New York the next year, completing his dissertation and making significant contributions to the representation theory of solvable Lie groups. Jon was Lou's first Ph.D. student at City University.

During the 1963–64 year when Lou was in Berkeley, he also introduced me to nilmanifolds and solvmanifolds (these are manifolds of the form G/H where G is a nilpotent or solvable Lie group H a closed subgroup). The most interesting case is when G/H is compact. Lou had written a number of important and path-breaking papers on solvmanifolds and nilmanifolds, including an extension of the Bieberbach theorem on space groups where n-dimensional Euclidean space is replaced by a connected and simply connected nilpotent Lie group. Lou, with Leon Green and Frank Hahn, had done some beautiful work [2] on analyzing when

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a one parameter subgroup of a solvable group G acts ergodically on the manifold G/H. Insightful conversations with Lou during this year inspired my own subsequent work in this direction over the next several years.

Although Lou and I did not work together on any research projects after this year in Berkeley, we talked about mathematics and other topics frequently and remained good friends. Lou continued his work on harmonic analysis on solvmanifolds and nilmanifolds with many interesting papers. The focus of his work then shifted to analysis of discrete Fourier transforms, where he developed new fast algorithms of interest in computer science. He applied harmonic analysis to problems in radar (analysis of the radar ambiguity function) and then to general mathematical problems in various aspects of signal processing. Our scientific paths crossed briefly once more just recently in our common interest in the phase reconstruction problem in crystallography, a problem in finite Fourier analysis.

I have many fond memories of working with Lou—his insight and intuition were marvelous, and it was a joy to work with him. I learned a lot about mathematics and how to do mathematics and about many other things. Lou was certainly what I would call "streetwise" (interestingly, a description that I see Tom Kailath uses as well to describe Lou), and I recall his recounting stories from his youth about outsmarting other kids and cleverly avoiding getting into fights, especially with kids bigger than he was. I am forever very much in his debt and will miss him.

Bertram Kostant

I met Lou Auslander for the first time when we were graduate students at Chicago in the early 1950s. It was an exciting time and place for mathematics. If I remember correctly, Lou's primary interest at that time was differential geometry. He, like so many others (including me), was highly influenced by Chern. After Chicago I remember a productive conversation with Lou in the 1950s on holonomy groups. The conversation certainly influenced a paper I was writing on that subject. However, the main interaction I had with Lou Auslander began after a lecture he gave, I believe, at MIT in the mid-1960s. After a long, heated discussion we both came away with a common exciting agenda: find the unitary dual of a type 1 simply connected solvable Lie group. The background for such an enterprise is as follows. Lou had written an important paper with Cal Moore on unitary representations of solvable Lie groups. As a consequence he was heavily armed with Mackey theory [8]. From Mackey to Moore to Auslander. On the other hand, I had seen a couple of years earlier that what the work of Kirillov, Borel-Weil, Harish-Chandra, and Gelfand had in common was a quantization of a symplectic structure on coadjoint orbits. Among other things I introduced the concept of polarization of a symplectic manifold. This term with this meaning, now well known, appeared for the first time in my subsequent joint paper with Lou. A very strong motivation for me in my collaboration with Lou was to show that what is now called geometric quantization could break new ground in representation theory. Besides Lou's earlier paper with Moore, there were preceding us other steps beyond Kirillov's nilpotent result. Bernat found the unitary dual of any exponential solvable Lie group. In the general case we faced coadjoint orbits which were no longer necessarily simply connected (more than one quantum line bundle per orbit). Worse, there could be no invariant real polarizations. Still worse was the problem of how to characterize type 1-ness. R. F. Streater visited MIT in the mid-1960s and complained to me that the 4-dimensional solvable Lie group he was studying (the oscillator group) had no invariant real polarizations, so how was he to find its unitary dual? I suggested using an invariant positive complex polarization. It worked. This was an encouragement for us.

Ph.D. Students of Louis Auslander

Clifford Perry (1965)
John Scheuneman (1966)
Jonathan Brezin (1967)
Robert Johnson (1969)
Richard Tolimieri (1969)
Carol Heinz-Jacobowitz (1972)
Harvey Braverman (1973)
Evelyn Mayer Roman (1973)
Sharon Goodman (1978)
Ephraim Feig (1980)
Bharti Temkin (1983)
Michael Vulis (1983)
Myoung Shenefelt (1986)
James Seguel (1987)
Michael Cook (1989)
Frank Bernard Geshwind (1993)
Jeffrey Litwin (1995)
Irina Gladkova (1998)

My collaboration with Lou was fun. Each week alternately either I would go to CUNY or he would come to MIT. It was also mutually educational. He taught me Mackey theory, and I taught him the ins and outs of geometric quantization. Together we were able to translate successfully the relevant aspects of the Mackey machine to the language of symplectic geometry. The final result was nicer than we had hoped for. Not only was the unitary dual neatly determined, but the condition for type 1-ness turned out to be expressible geometrically in an elegant way. The paper [4] was published in *Inventiones* in 1971. It is not the best-written paper. A much nicer version, which gets to the heart of the matter in a clearer way than we had seen it, appears in a Bourbaki seminar (1973–74) by Michèle Vergne [9].

I have fond memories of Lou. He brought to the table excitement, brilliance, and marvelous insights. After our paper was written Lou liked to tease me by telling a story in gatherings about our lunch times together. When I visited New York, he would take me out for an elaborate meal. When he came to Boston, I would take him to the sandwich machines in the basement of MIT. (I had no idea at the time how painful this was to him.)

My collaboration with Lou Auslander was one of the best collaborative experiences I have ever had. I am very grateful to him.

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Anna Tsao

I met Lou Auslander while a member of the technical staff at AT&T Bell Laboratories in 1987. It was a pivotal moment in my life, as Lou became a mentor, colleague, and above all a close friend who had a major impact on both my professional and personal development. At Bell Labs I was assigned the task of designing a parallel algorithm for adaptive beamforming. A critical part of the processing was solving a symmetric eigenvalue problem. Lou had some intriguing ideas about computing eigenvalues of large dense matrices by thinking of the so-

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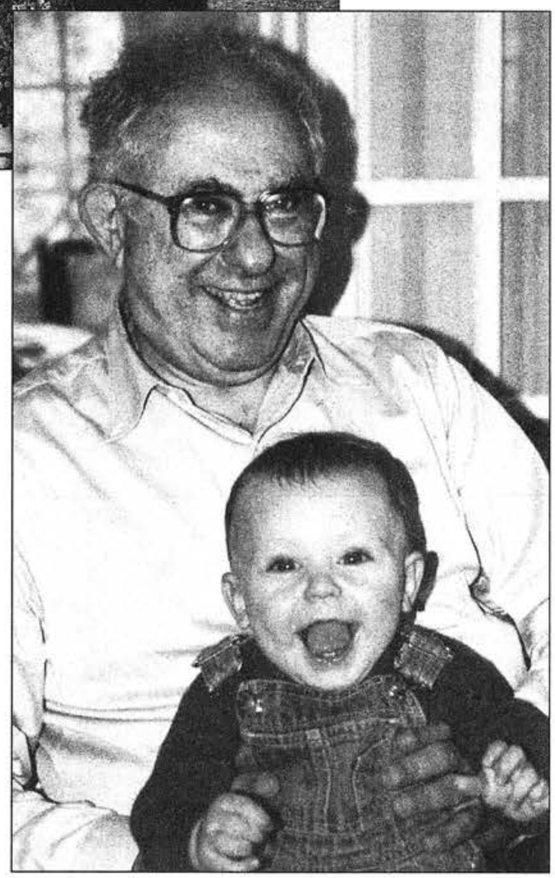
lution as a direct sum decomposition of certain commutative algebras. Since I was trained as a pure complex analyst, I was apprehensive about plunging headlong into areas in which I had a less-than-comprehensive background. Lou would exhort me not to be concerned because (paraphrased) "Mathematics is like a river. You just jump in some place, and the current will help take you where you need to go." Our subsequent collaboration [6] on eigenproblems after I joined the Supercomputing Research Center led to considerable activity in numerical linear algebra.

Shortly thereafter Lou decided to join DARPA as the program manager for the Applied and Computational Mathematics Program. To Lou the significant personal sacrifice of putting his research aside for two years was more than offset by the opportunity to make a difference to both the Department of Defense mission and to mathematics in general. And make a difference he did, in profound ways. Several programs that Lou started led to spectacular mathematical and scientific achievements that are receiving wide attention in the scientific and Department of Defense communities. Two examples are wavelets and the Fast Multipole Method for solving the Helmholtz equation. The impact on important DoD problems resulting from the significant funding in these areas by Lou and his DARPA successors has been highlighted in briefings to members of Congress and the Pentagon numerous times, including detailed briefings to officials such as the then Secretary of Defense William Perry.

Lou's success at DARPA was a direct result of his ability to inspire others with his vision of mathematics as a cohesive, integrated, and powerful discipline that can open exciting new vistas to be conquered when combined with science and engineering. He was considered to be a singularly effective mathematician and program manager at DARPA who actively sought out and created new mathematical opportunities. His quick intellect and congenial manner enabled him to engage a wide range of program managers from competing offices and disciplines in meaningful discussions of their technical programs which led to joint formulation of the underlying mathematical challenges. His success in this is legend at DARPA and required great energy, objectivity, creativity, and knowledge of the breadth of mathematics. Often after first learning an entirely new field, he would then identify the appropriate mathematical expertise needed to meet these challenges and seek out experts in those areas to team with the application scientists. On other occasions he would draw on his considerable scientific insights and abilities to identify application areas to which current areas of mathematical activity could make an impact. Lou's tireless, personal dedication to demonstrating the power of mathematics in science and engineering not only resulted in substantial funding of mathematical research at DARPA but influenced other program managers to incorporate more mathematical directions into their own programs. Lou's extended vision of the role of a mathematics program manager lives on as a guiding principle of DARPA's Applied and Computational Mathematics Program and is one which I, as a current DARPA program manager, try to emulate.



Auslander with granddaughters Michelle and Danielle, top photo, and grandson Taran, bottom.

Lou's research interests and collaborations in recent years were extremely diverse. Lou's outlook is exemplified by the fresh, original approaches that characterized his research, in collaboration with several others, on the Fourier transforms. Lou was convinced of the significant role that core mathematics should play in the design of computational algorithms. To elaborate, he once stated that the almost endless capability that mathematics provides to reformulate problems and solutions should be exploited in seeking new algorithms. He observed that mathematicians are often surprised that mathematically equivalent formulations can have radically differing computational properties. This duality of pure math and computational applications is beautifully presented in Lou's AMS *Bulletin* article [5] with R. Tolimieri on the Fourier transform, which additionally enticed many young mathematicians into harmonic analysis. He was involved in a long-term effort to investigate how the algebraic structure of Fast Fourier Transform (FFT) algorithms could be exploited to automatically implement optimized FFT algorithms. The mathematical culmination of Lou's interest in this subject was a group representation theoretic result obtained jointly with J. R. Johnson and R. W. Johnson shortly before Lou's death, in which "all" possible additive FFT algorithms are characterized mathematically [7]. Although the full implications of this result will take some time to realize, it has already led to multidimensional FFTs that have significantly improved computational properties.

Lou left a rich legacy of professional contributions to mathematics. In addition, he gave those of us who had the opportunity to know him as a friend and colleague may wonderful memories of his warmth, generosity, and wisdom.

Thomas Kailath

Coordinator's Note: This segment is a lightly edited version of an electronic message sent by Thomas Kailath to "Friends in the Stanford Manufacturing Group" shortly after Lou Auslander's death.

Not all of you may have heard that Lou Auslander passed away last week. This sad news, which I received while traveling, was especially poignant because Lou was going to be visiting the Bay Area later this month.

Lou, as some of you know from direct experience, was a very unusual man. He won a fine reputation in several different fields of mathematics before turning in the last dozen years or so to the study of multidimensional Fourier transforms and to the design of signal sets for communications and radar. These areas bring difficult mathematical challenges, but they also got Lou very interested in applications. There are mathematicians who have difficulty coping with the informal way in which engineers often handle mathematical discussions, but not Lou. I remember first meeting him at some signal processing workshop in the mid-1980s. He seemed to enjoy the meeting and had discussions with a variety of people. Lou was then a consultant for the mathematics department of IBM Research, whose director, Shmuel Winograd, had charged me with putting together a summer program on the Mathematics of Signal Processing for the Institute for Mathematics and its Applications in Minneapolis. Seeing Lou in action led me to invite him to be on the organizing committee, of which he soon became a dominant member, expressing himself quite freely and caustically, which will not surprise many of you. However, Lou had many good ideas, several of which we adopted.

A couple of years later he landed himself at DARPA as program manager for Mathematics. [How this came about is a story in itself — briefly (and perhaps not completely accurately), a few years earlier Lou had taken it upon himself to complain directly to the director of DARPA that the value of mathematics was not adequately recognized by DARPA. His complaint worked, but the program that was launched was floundering after a while, so the director apparently insisted that Lou come and fix the problems.] However, by the time Lou arrived at DARPA, there was no money left in the Mathematics budget; moreover the program had found itself in the Materials (later Defense) Science Division. Undaunted, Lou began to adapt to this new environment. Exposure to various discussions and seminars convinced him that though there was a lot of interest in the manufacture of various new types of materials, the tools of control, optimization, signal processing, and simulation were not much used by the materials scientists working on these problems. Lou called me up to discuss the issues and then to suggest that we take a look at filling this gap. While I agreed that our tools could help, as a theoretical engineer who had never worked with real equipment, I was reluctant to get involved. "I only write papers," I said, "while here it looks as if you really want something done." However, Lou persisted, with the promise (possible only by DARPA managers, or perhaps usually only dared to be made by them) of freedom to explore whatever we found to be best, backed up by reasonably generous funding. He added that it was OK if we failed. Put that way, it was an offer we couldn't refuse.

As you know, thanks to our environment of great students and cooperative colleagues, we were able to rise to Lou's challenge and to vindicate his vision of the importance of control and signal processing in manufacturing. Lou was as pleased as we were when one of our efforts won the 1994 Outstanding Paper Prize of the *IEEE Transactions on Semiconductor Manufacturing*, a journal we had hardly been aware of a few years ago. Lou's successor at DARPA, Jim Crowley, built on Lou's initiative by winning approval for a much larger MURI (Multidisciplinary University Research Initiative) program in modeling, simulation, and control of materials manufacturing processes, now under way with six university teams. Some technology

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transfer has already taken place, and I have no doubt that even in the relatively conservative semiconductor manufacturing industry we shall see increasing use of these tools.

However, theory in manufacturing was only one of Lou's initiatives at DARPA. Other major ones were on wavelets (with both classified and unclassified applications), advanced radars (one of his personal research areas), matrix-oriented computing architectures, and several others far beyond my ken.

Our project, and the related ones in industry, gave me the pleasure of many discussions with Lou. He was always available as a source of advice on a variety of issues, including some very prickly ones. He attributed a lot of his attitudes and personality to his grandmother and mother, early immigrants from Eastern Europe whose intelligence, determination, and common sense made them successful despite their lack of formal education. In fact, one of Lou's epitaphs might well be "He was a 'streetwise' mathematician". But that is only one of them. He was too rich a personality, and his range of contributions is too wide to be captured in a single phrase.

We shall really miss him, a thought that might bring a chuckle to his spirit, wherever and whatever it is now—perhaps, in Shelley's words, "an unbodied joy whose race is just begun."

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