In memoriam: Klaus Keimel (1939–2017)

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KLAUS KEIMEL was born on September 22, 1939 and died of cancer November 18th, 2017 at the age of 78. Not only was this a grievous loss for his beloved wife, children, and grandchildren, but also for the many and varied colleagues whom he befriended and fruitfully interacted with around the world. He will be remembered by his students as an engaging teacher and adviser and a gentleman-professor. His colleagues at Darmstadt

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University of Technology benefitted both from his collegiality, principles, attitudes, and demeanor and his extensive service to the department, which included a term as Dean of the School of Mathematics. He served as an editor of *Semigroup Forum* from 1976 to 1995. He was also editor of *Order* from 1984 to 2002 and of *Beiträge zur Algebra und Geometrie* from 1992 on.

KLAUS KEIMEL began his mathematical studies at the University of Tübingen and met KARL HOFMANN there around 1961, with whom he wound up writing a Master's Thesis. There were a number of Tulanians visiting Tübingen—PAUL MOSTERT, ANNE and SIGMUND HUDSON, and W. CHARLES HOLLAND JR., a group theoretician and student of PAUL CONRAD's; topological semigroups were in the air. When HOFMANN returned to Tulane in 1963, Klaus came to Tulane to deepen his studies and to complete a dissertation on locally compact abelian semigroups, which he linked up with the geometry of convex cones. PAUL MOSTERT and KARL HOFMANN were working rather intensively on a book on compact semigroups that was closely linked to the very visible culture of algebraic topology and topological semigroups that ALEXANDER DONIPHAN WALLACE had created at Tulane University and Louisiana State University, from where it had spread widely, but notably in the southern United States; its publication record as a community had become widely noticed. The graduate student KLAUS KEIMEL was assigned to read the chapters of that book on compact semigroups as they were generated, and so he commented and discussed what he learned from his reading with the authors of the book, which appeared in print in 1966. Entitled the *Elements of Compact Semigroups* [7], this book incorporated many of the developments in topological semigroup theory as well as significant new advances that required new mathematical tools, notably in the area of compact transformation groups and Lie group theory, that reached well beyond the earlier semigroup theory. And KLAUS KEIMEL, in his formative years, was in the midst of this fermenting field as one of the first readers of the *Elements*. Irrespective of what the future would hold for him, topological semigroups were at the foundation of his mathematical education. KLAUS KEIMEL returned to the University of Tübingen, where he obtained his doctorate. He moved on to Paris in late 1965, where he joined an environment supporting algebraic semigroup theory represented there by PAUL DUBREIL and his wife MARIE-LOUISE DUBREIL-JACOTIN, who became his mentor for his “Thèse d'État,” completed in 1971. Through this work he also became familiar with at least two of the founders of the French school of semigroups. KLAUS KEIMEL then returned to Germany in 1971 and was appointed to a Professorship at Darmstadt in the early seventies, a position he held until his retirement in 2004. In the following years he remained active there as a Professor Emeritus.

KLAUS KEIMEL's early research in semigroups consisted of several papers covering uniquely divisible commutative locally compact semigroups and their connections with cones [8, 11], and investigations of cones as semigroups and other ordered semigroups [9, 10, 15]. A substantial body of work on the representation of semigroups, lattice-ordered groups, rings, and general algebraic systems via sections of sheaves appeared in the early seventies [12–14, 16]. Sheaf representation was an interest that carried into his later career [1]. His multidisciplinary approach, which had partly developed in Paris, found its expression in the memoir [6] on duality theory in the context of lattices.

Klaus Keimel's closest continuing connections with semigroup theory involved aspects of a theory of general cones, beyond just those embedded in vector spaces. Various aspects of this theory reappeared throughout his career. In the nineties he collaborated with WALTER ROTH, who began his mathematical career at Darmstadt. They worked on extending functional analysis to cones [19], a topic Klaus pursued further on his own [17]. From mid-career on Klaus was actively involved in topics coming from mathematical foundations of computer science, semantics and programming in particular. With one of his students REGINA TIX [20] he studied cone models for probabilistic programming and computation, a theory which recently he significantly extended with computer scientist GORDON PLOTKIN [18].

The extensive work of KLAUS KEIMEL, with students and colleagues, in mathematical foundations of computer science had another significant connection in semigroup theory. JIMMIE LAWSON in his dissertation and research in the late sixties introduced an attractive class of commutative idempotent compact semigroups. Shortly thereafter DANA SCOTT introduced a class of complete lattices named by him "*continuous lattices*." These objects and their later generalizations, "*continuous domains*" significantly impacted developments in logic, computer science, particularly semantics, and topology. Indeed, a special conference "Fifty Years of Domain Theory" took place at Oxford in July, 2018.

In 1974 KARL HOFMANN and AL STRALKA showed (in a somewhat roundabout way) that Scott's lattices and Lawson's semilattices were alternative formulations of the very same objects. This discovery turned out to provide an immensely fruitful link between semigroup theory and order theory in a form which has produced numerous applications to this very day. And KLAUS KEIMEL with his background in semigroups and in algebra was incredibly instrumental to further this insight in many ways (see, e.g., [2]), particularly in his contributions to [4] and, notably, to the re-edited and augmented version [5] whose preparation for final publication was carefully and laboriously orchestrated by KLAUS KEIMEL in Darmstadt. And so, even if many mathematicians know KLAUS KEIMEL best for his contributions to order theory, continuous lattices, or their later manifestations and generalizations as "*continuous domains*," for him semigroup theory was a crucial ingredient in this mix.

Because of his extensive knowledge of mathematics, and as time went by, theoretical computer science, and his notable friendliness and kindness, KLAUS KEIMEL has been a great builder of bridges—mathematical bridges between diverse specialities and human bridges of personal relationships with students and a diversity of international colleagues. One of his fairly recent coworkers in a collaboration that grew out of his interpersonal bridge building, is the respected French computer scientist JEAN GOUBAULT-LARRECQ. Considering Klaus Keimel he remarks: "*His talents were not confined to domain theory, and he had been active in various other fields of mathematics, too, in analysis and algebra for example. He could surprise you by telling you about K-theory, about sheaves, or about traces in C^* -algebras.*" JEAN-ERIC PIN writes: "*Klaus was a personal friend and I owe him a strong debt of gratitude. He helped me a lot at the beginning of my career; he is the person who suggested me to work in automata theory.*" In the preface of a special issue of *Mathematical Structures in Computer Science* [3] dedicated to Klaus on the occasion of his sixty-fifth birthday and retirement, the guest editors MARTÍN ESCARDÓ, ACHIM JUNG, and THOMAS

STREICHER write: “*With this volume we are honouring a scientist who can truly be said to have built bridges between mathematics and theoretical computer science. Having started out as a pure mathematician with interests in ordered algebraic structures, Klaus Keimel in the early seventies enthusiastically joined the effort to explore the connections between his mathematical speciality and Dana Scott’s newly discovered continuous lattices. . . . He uncovered links to universal algebra, game theory, set-valued functions, functional analysis and, especially, measure theory.*”

We will miss you, Klaus, as a mathematician, but especially as a friend.

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