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OBITUARY

# Axel Ruhe 1942–2015

**Åke Björck**[1] · **Lars Eldén**[1]

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Axel Ruhe passed away April 4, 2015. He was cross-country-skiing with friends in the Swedish mountains when after 21 km he suddenly died. He is survived by his wife Gunlaug and three children from his first marriage.

After finishing high school in Jönköping in 1961, Axel got his Bachelor's degree at Lund University the following year. He then started as a Ph.D. student in numerical analysis under the supervision of Carl-Erik Fröberg, who was one of the computer pioneers in Sweden and together with Niels Ivar Bech founded the journal BIT in 1960. Fröberg was the Editor-in-Chief of BIT for the first 32 volumes.

Axel's first research area was eigenvalue algorithms. In a paper on Jacobi's method for normal matrices he continued the work of H. H. Goldstine and P. Eberlein. The main part of his Ph.D. thesis in 1970 builds on work of V. N. Kublanovskaya, whose

✉ Lars Eldén
lars.elden@liu.se

[1] Department of Mathematics, Linköping University, Linköping, Sweden

development of the staircase algorithm for computing the Jordan normal form was largely unknown outside the Soviet Union. The main advantage of this QR like algorithm was that it could handle both derogatory and defective matrices. Axel developed it into a practical numerical algorithm using Kato's perturbation theory to see how one multiple eigenvalue split into several groups when the matrix was perturbed.

In 1970 Axel moved to Umeå University, where he was appointed full professor in 1975. Here he continued the work on the staircase algorithm together with his student Bo Kågström, whose later developments made it the standard algorithm for Jordan and Kronecker normal forms. In 1980, he took up research on the Jacobi method again and demonstrated a relation between Jacobi's method and inverse iteration. Following advice from Gene Golub he used the Jacobi method to solve an open problem in matrix approximation. His result was published in a paper with the catchy title "Closest normal matrix finally found!" in BIT 1986.

In Umeå, together with Per-Åke Wedin, Axel developed Gauss–Newton methods for nonlinear least squares problems. Their paper on separable least squares is well cited. Axel would later return to this problem, working with his student Kenneth Holmström. Another area that Axel pursued in Umeå was nonlinear eigenvalue problems, and he developed a linearization algorithm that has global convergence. After he had moved to Gothenburg in 1983, he continued this work together with his student Jaques Huitfeldt, and applied it to bifurcation problems.

In the early 1970's, when it was clear that the QR algorithm was the winner for dense eigenvalue computations, Axel turned his attention to large, sparse matrices and the application of algorithms for linear systems (e.g. SOR and conjugate gradients) to eigenvalue computations. Together with his student Thomas Ericsson, Axel developed the spectral transformation Lanczos method (STLM). This work is often cited and several software packages such as the SAAB variant of the ASKA FEM package. John Lewis and coworkers at Boeing included a block version of STLM in the NASTRAN package. Also FEMLAB developed by COMSOL, a spin off from KTH in Stockholm, has implemented this approach.

After 1992 Axel developed rational Krylov methods, where spectral transformation Lanczos or Arnoldi methods were used with several shifts in one run. A key ingredient was to use vectors produced during Rayleigh quotient iteration to find approximations to the next eigenvalues after the first had converged. Jointly with his student Daniel Skoogh, Axel applied these ideas to reduced order models of linear dynamic systems. Axel was one of the editors and contributors to *Templates for the Solution of Algebraic Eigenvalue Problems, a Practical Guide*, published by SIAM.

Throughout his career Axel had an interest in methods for statistical computing. An important contribution is a paper from 1984 on PLS (partial least squares), which is a method invented by H. Wold in the 1970's for computing low rank least squares models. Today PLS is used extensively in chemometrics as well as many other fields. Axel noticed that the original PLS algorithm is mathematically equivalent to a few steps of the Golub–Kahan bidiagonalization method and thus a Krylov subspace method. This observation has been important for understanding the properties of PLS.

Axel also realized the potential of Krylov methods in information retrieval. Together with his student Katarina Blom, he showed that a couple of steps of Golub–Kahan

bidiagonalization were enough to get as good performance as a truncated SVD model of much larger rank.

Through Carl-Erik Fröberg, who supervised his dissertation, Axel became involved with BIT and was made a member of the Editorial Board already in 1974. In 2003 he became the Editor-in-Chief of BIT Numerical Mathematics, succeeding Åke Björck. He promptly introduced a new cover design featuring the four Nordic flags as well as a pictorial outlining of the continents of the world. During his term Axel widened the scope of BIT and renewed and enlarged the Editorial Board.

Axel made several longer visits abroad. In 1969 he spent two months in Leningrad at Akademia Nauk. He visited Stanford University in 1973 and 1982, and spent the academic year 1977–1978 at University of California, San Diego and 1994–1995 at Berkeley. In 1987 he visited Academic Sinica in Wuhan. Among his international assignments can be noted that he served as Chair of the committee for the prestigious A. S. Householder Award given for the best dissertation in numerical linear algebra.

Together with Bo Kågström Axel organized the workshop on Matrix Pencils at Pite Havsbad in March 1982. The workshop attracted top-researchers from 14 countries and each morning and at lunch breaks, they had the opportunity to practice country-cross skiing on the snow covering the frozen Gulf of Bothnia, an exotic activity often led by Axel.

Axel was lively and always full of energy. His enthusiasm for numerical linear algebra was particularly apparent when he gave a talk. Already as a Ph.D. student his brilliance made a deep impression in younger students. His talks were noted for handwritten overhead transparencies that were very informative. Although he did not speak Russian fluently he never hesitated to give a talk or after dinner speach in the native language when in Russia.

Outside of his scientific life, Axel had several interests. He was a member of the Gothenburg Royal Society for Arts and Sciences. He put a lot of effort into his work in the Swedish branch of the Christian peace movement and the International Fellowship of Reconciliation (IFOR). Axel also was active in the Cohousing movement. Axel had wide cultural interests, and he was a music lover and also very well-read in literature.

Axel practiced many activities in his spare times. Apart from cross country skiing he sailed together with his wife Gunlaug both in the Swedish archipelago and in the Mediterranean Sea. His love of water also showed in other ways. During his sabbatical in San Diego he learnt surfing. Many of his colleagues also remember that he always brought his bathing suit along at conference excursions. He always managed to swim even in the cold mountain lakes in Norway.

Axel made many profound contributions to numerical linear algebra and scientific computing over the years. A bibliography with cross references compiled in February 2015 can be found at http://www.netlib.org/bibnet/authors/r/ruhe-axel.pdf.

It is very sad and a great loss that Axel is not with us anymore. He will be long remembered.

Åke Björck and Lars Eldén