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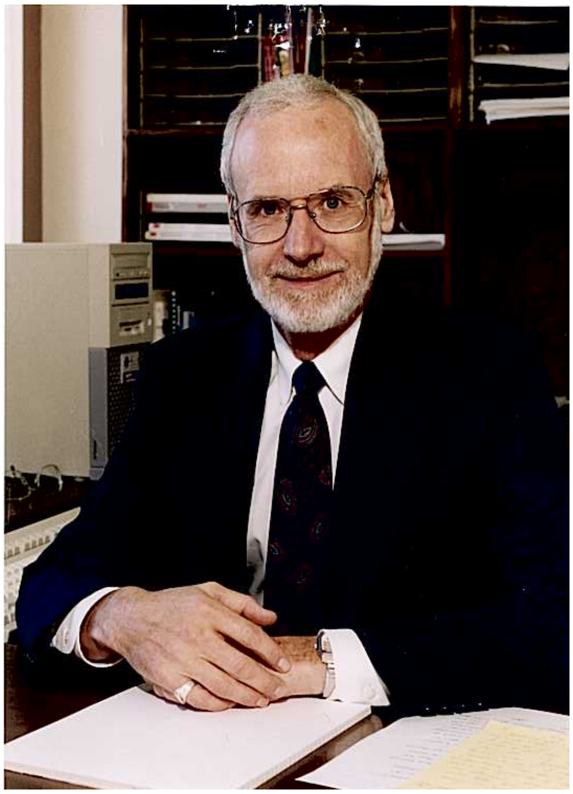
DEDICATION TO ALAN GEORGE

This special volume of Electronic Transactions on Numerical Analysis is dedicated to Alan George, an intellectual forefather of the combinatorial scientific computing (CSC) community, who celebrated his 62nd birthday on November 9, 2005. Alan has made many significant contributions to CSC especially in sparse matrix algorithms, numerical linear algebra, and mathematical software. At the First SIAM Workshop on Combinatorial Scientific Computing held at San Francisco in February 2004 (when he had turned sixty), Alan was honored with a plaque for his pioneering contributions to CSC as a researcher, teacher and mentor. The CSC community congratulates Alan on this milestone in his life, and wishes him continued success in the future. In this tribute, we include a brief biographical sketch of Alan, describe his research contributions, mention the names of his students, and list all of his publications to date.



Alan George was born November 9, 1943 in Lloydminster, a town that straddles Saskatchewan and Alberta, to John Edward George and Margaret Ann Brown. After completing his early education in public schools in Alberta and Saskatchewan, he attended the University of Alberta where he received a Bachelor's degree in mathematics in 1964. He also received a Master's degree in computer science in 1966

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from the University of Alberta. Alan worked as an instructor at Alberta for a year, and then enrolled for graduate studies at Stanford University, where he received a Ph.D. in computer science in 1971. His advisor was Professor George E. Forsythe, the founding chair of the computer science department at Stanford, and an early leader in the emerging field of computer science and in the Society for Industrial and Applied Mathematics.

After graduating from Stanford, Alan joined the computer science department at the University of Waterloo. Here he began his research in the field of sparse matrix computations, developing graph-theoretic models, novel algorithms and the SPARSPAK software library for solving sparse systems of linear equations by direct (factorization) methods. He rose rapidly through the academic ranks, becoming the youngest professor in the computer science department at Waterloo. In 1980 Alan began his career in university administration as Dean of the Faculty of Mathematics, serving until 1986. He moved to the U.S. in 1986, holding the position of University Professor of Mathematics and Computer Science at the University of Tennessee at Knoxville and Distinguished Scientist at the Oak Ridge National Laboratory. In 1988 Alan returned to the University of Waterloo as Vice-President, Academic and Provost, and completed a five-year term in that position on June 30, 1993. After five years of research and teaching in the department of computer science, he served a second term as Dean of the Faculty of Mathematics from 1998 to June 2005. In 2003 Alan became Associate Provost of Information Systems and Technology, a position that he continues to hold; he also serves now as interim Vice President of Research at Waterloo.

Alan George's broad research interests involve large scale scientific computation and related aspects of mathematical software. He is the author or co-author of 108 articles (currently!), two books, and has co-edited two other books. With his students, he has developed a widely-used mathematical software package, SPARSPAK, for solving large sparse systems of equations and sparse least squares problems.

Nested dissection is a technique he invented in his early years at Waterloo, for ordering sparse matrices from the finite element method for sparse Cholesky factorization. For the $n^{1/2} \times n^{1/2}$ grid corresponding to a model problem, Alan showed that whereas a natural ordering would require $\Theta(n^2)$ operations, a nested dissection ordering would lead to only $\Theta(n^{3/2})$ operations in the sparse factorization. This technique was readily generalized to planar graphs and three-dimensional meshes with bounded aspect ratios of the elements. In recent years, with the development of high quality graph partitioning algorithms based on spectral graph theory and the multilevel paradigm, nested dissection has become the method of choice for ordering sparse matrices for factorization.

Together with Joseph Liu, he developed the quotient graph data structure to represent the sequence of elimination graphs in sparse Cholesky factorization in a semi-implicit and space-efficient manner. This factorization creates many *fill elements*, zero elements in the original matrix that become nonzeros in the factor. The quotient graph model enables one to compute implicitly the data structure for a sparse Cholesky factor in no more space than that required by the original matrix. The space-efficient representation of the filled graph is achieved by continuing to represent edges incident on eliminated vertices and identifying fill edges using paths of length at most two in the graph model. Alan and Joseph used the quotient graph to design an efficient symbolic factorization algorithm that computes a data structure for the sparse Cholesky factor, and also to implement the minimum degree ordering algorithm.

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This work led to a comprehensive suite of algorithms and software for solving large, sparse, symmetric positive definite systems of equations and least-squares problems. The programs, developed by Alan George, Joseph Liu, and Esmond Ng, were included in a software library called SPARSPAK, and this library has been licensed for use in more than 150 industrial, academic, and research institutions in over twenty countries.

The design of SPARSPAK included several novel features. This package, dating back to 1975, exhibited several features of object-oriented design and modern software engineering practice. It was organized in a modular fashion into a collection of routines for the various subtasks involved in solving systems of sparse, linear equations: ordering, symbolic factorization, numerical factorization, and triangular solution. The package had a friendly user interface, with short and simple parameter lists, and it supported automatic storage allocation. Graceful and informative error-handling routines were included as well. The design of SPARSPAK's user interface was described by Alan and Joseph in an ACM Transactions on Mathematical Software article in 1979.

The graph models and algorithms developed in this work were discussed in a book that Alan George and Joseph Liu published in 1981, *The Computer Solution of Large, Sparse, Positive Definite Systems.* The book popularized the distinctive approach that Alan and his colleagues brought to their work in sparse matrix computations: development of suitable graph models for the problems; mathematical formulations and proofs of properties that are used to solve the problems; the design of practically efficient algorithms based on these formal mathematical results; analysis of the worst-case time-complexity of the algorithms when feasible, and when that is too complex, such analyses for the model problem; careful attention to the design of space-efficient algorithms; and implementation and computational verification of the practical efficacy of the algorithms on a collection of test problems from various applications. The care and time that Alan took to communicate the results of his work enabled researchers following him and scientists from other research areas to gain a thorough understanding of the field of sparse matrix algorithms. The book served to educate the next generation of researchers in sparse matrix computations, and has influenced the approaches that researchers in combinatorial scientific computing bring to their research.

Together with Michael Heath, then at Oak Ridge National Laboratory and currently at the University of Illinois, Alan developed the first effective algorithm for computing the orthogonal factorization of a sparse matrix. Exploiting the fact that the nonzero structure of the triangular factor in the orthogonal factorization of a sparse matrix A is identical (up to multiplication of rows by ± 1) to that of the Cholesky factor of the matrix $A^T A$, they developed an algorithm for computing the orthogonal factorization *in place*, i.e., in the space allocated to the triangular factor and an additional row. The matrix A was transformed by rows, with nonzeros from each row annihilated by a sequence of Givens rotations. The relationship with Cholesky factorization also meant that data structures for the triangular factor and ordering strategies such as nested dissection and minimum degree that were developed for Cholesky factorization could be employed here. The rows of the matrix to be factored could then be ordered to reduce the computational work. The efficient algorithms developed in this work were used to solve large-scale least-squares problems involving millions of observations from the National Geodetic Survey.

The work on Givens orthogonalization led to graph models and data structures

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for other factorizations of nonsymmetric matrices. In subsequent work, Alan George, Esmond Ng and Joseph Liu described data structures for sparse Gaussian elimination with partial pivoting and orthogonal factorization with Householder transformations.

When Alan moved to the University of Tennessee and Oak Ridge, the first commercial parallel computers were becoming available. Alan and his colleagues there, together with Joseph Liu, designed and implemented the first parallel algorithms for sparse Cholesky factorization. Their work concerned the discovery of concurrency in sparse matrix computations, task decomposition, the construction of a suitable task graph to discover the precedence constraints that tasks must satisfy, and mapping and scheduling the tasks on the processors in order to balance the work load and reduce the communication costs. While parallel architectures have changed significantly from the 1980's, the algorithmic paradigms that they discovered continue to determine how sparse matrix computations are performed on parallel computers.

With Eleanor Chu, Alan has written several papers on the parallel computation of the orthogonal factorization of a sparse matrix, and a book on algorithms for computing Fast Fourier transforms on serial and parallel computers. In recent years, together with Khakim Ikramov, Alan has published papers on varied topics such as the growth factor in Gaussian elimination for special classes of matrices, symmetric quasi-definite matrices, the polar decomposition, etc.

Alan has served with distinction as an editor for *The Electronic Transactions on Numerical Analysis* as well as several other journals: *The ACM Transactions on Mathematical Software*, *SIAM Journal on Scientific and Statistical Computing*, *Linear Algebra and its Applications*, and *Aequationes Mathematicae*. He has also been a leader in many professional organizations. He served as chair of the Association of Computing Machinery's (ACM) Special Interest Group on Numerical Mathematics from 1981 to 1983, and as a member of the SIAM Council from 1987 to 1990. He served for many years on the committee organizing the Householder meetings on numerical linear algebra, and hosted the one held in Waterloo in 1984. He has been a consultant to various companies and government agencies in Canada, the United States, and Britain, and has served on advisory or governing boards for a number of academic institutions and research institutes.

Alan has received several honors during his career. In 1982 he was awarded the George E. Forsythe Memorial Prize for Leadership in Numerical Mathematics by the ACM. He is a Fellow of the Institute for Electrical and Electronics Engineers, a Fellow of the Institute for Mathematics and its Applications, and a Fellow of the Royal Society of Canada. In 1992, he received the Governor General's Commemorative Medal awarded on the 125th anniversary of Canada.

Perhaps the best legacy that Alan has for us in combinatorial scientific computing is his appreciation for the elegance of simplicity. Joseph Liu, in a talk at a conference at Stanford University in January 2004 to celebrate Alan's sixtieth birthday (and also the sixtieth birthdays of two of his colleagues, Jim Varah of the University of British Columbia and Michael Saunders of Stanford; the conference was organized by Michael Friedlander, Gene Golub, Chen Greif and Esmond Ng), recounted several lessons that he had absorbed from Alan. Foremost is to "think simple"—Alan has the gift as a successful pioneer in sparse matrix algorithms to find simple solutions to problems from a clutter of possibilities. Joseph mentioned the high value that Alan placed on communicating his research results as clearly as possible, and in finding elegant approaches to the design of sparse matrix software. Joseph also added that he learned from Alan to recognize the role that failed attempts play in ultimately solving

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a problem.

Alan has spent eighteen years in the senior administrative ranks at the University of Waterloo. He is known to be decisive, making up his mind quickly once he has marshaled the facts, and willing to make tough decisions when needed. David Johnston, President of the University of Waterloo, says of Alan: "No one has served his University with greater devotion and wisdom than Alan George has at Waterloo. He is a man of old-fashioned virtues—selfless, courageous, brimming with integrity—and a long-term visionary." Amit Chakma, Vice President, Academic and Provost, adds: "Alan is a committed senior member of the Waterloo family, having served in more leadership roles than any other administrator. This is a recognition of his superb leadership qualities, and a sign of his loyalty to Waterloo. Alan's most significant contribution to Waterloo, in my opinion, is helping to create a culture of excellence, as a relentless champion of quality and a strong advocate for excellence."

Those of us who are colleagues of Alan have been privileged to see his vision, integrity, leadership, and passion for excellence; we have also been blessed by his friendship. As we celebrate this special milestone in Alan's life, we look forward to many years of fruitful interactions with him!

Students of Alan George.

List of PhD students.

1. Joseph W-H. Liu
2. Gaston H. Gonnet
3. David R. McIntyre
4. Esmond G-Y. Ng
5. Hamza Rashwan
6. Eleanor Chu
7. Fletcher Lu

List of Master's Students.

1. Kristine W. Kwok
2. Andy Haycock
3. Humphrey H. Yang
4. Yik-Man Lau
5. Eng-Wee Chionh
6. John Towers
7. Alex Liu
8. John L. Drummond
9. Wing Hong Wong
10. Lamees Abourahma
11. Rod Affleck
12. Ye Yang
13. Shae Armstrong
14. Gonzalo Middleton
15. Freddy Chik
16. David Marotto

List of Publications.

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