Software Product Description

PRODUCT NAME: Digital Extended Math Library for OpenVMS[1], Version 2.0 **SPD 31.67.01**

DESCRIPTION

Digital Extended Math Library (DXML) is a set of mathematical subroutines that are optimized for Digital architectures. Four libraries are included, covering the areas of Basic Linear Algebra, Linear System and Eigenproblem Solvers, Sparse Linear System Solvers, and Signal Processing.

The Basic Linear Algebra Library includes the industry-standard Basic Linear Algebra Subprograms (BLAS) Level 1, Level 2, and Level 3. Also included are subprograms for BLAS Level 1 Extensions and Sparse BLAS Level 1.

The Linear System and Eigenproblem Solver Library provides the complete LAPACK package developed by a consortium of university and government laboratories. LAPACK is a new, industry-standard package offering an extensive set of linear system and eigenproblem solvers. LAPACK utilizes blocked algorithms that are better suited to most modern architectures, particularly ones with memory hierarchies. LAPACK will supersede LINPACK and EISPACK for most users.

The Sparse System Library provides a set of iterative Sparse Linear System Solvers. The solver design is modular and matrix-free, allowing future expansion and easy modification by users. A basic set of storage methods, preconditioners, and iterative solvers is provided.

The Signal Processing Library provides a basic set of signal processing functions. Included are one-, two-, and three-dimensional Fast Fourier Transforms (FFTs), grouped FFTs, Convolution, Correlation, and Digital Filters.

All DXML subprograms are optimized for the supported hardware platforms. Some key computational modules may be written in assembler language. Optimization techniques include traditional optimizations such as loop unrolling and loop reordering. DXML subroutines also provide efficient management of the hierarchical memory system, using techniques such as the following:

- Reuse of data within registers to minimize memory accesses
- Efficient cache management
- Use of blocked algorithms that minimize translation buffer misses and unnecessary paging

Since DXML routines can be called from all languages that are supported by the OpenVMS calling standard, the library provides optimized computation for applications written in languages other than FORTRAN. Where appropriate, all routines are available in both real and complex versions, as well as in both single and double precision (D and G format).

The OpenVMS version of DXML also provides a special vector library that supports and is optimized for the VAX Vector Architecture. The vector library uses advanced algorithms tailored to specific operational characteristics of the VAX Vector Architecture.

BLAS Library Contents

Linear algebra operations are fundamental to vectorized mathematical applications and many libraries of linear algebra subroutines exist throughout the computer industry. The DXML BLAS library contains the most commonly used linear algebra subroutines.

The DXML linear algebra library contains six groups of subroutines at three levels:

- Basic Linear Algebra Subroutines (BLAS) Level 1
- BLAS Level 1 Extensions
- BLAS Level 1 Sparse Extensions
- BLAS Level 2
- BLAS Level 3
- BLAS Level 3 Extensions

BLAS Level 1 (Scalar/Vector and Vector/Vector Operations)

The Level 1 BLAS provide a set of elementary vector functions, operating on one or two vectors. These are typically very small subroutines and depend on assembly language or compiler inlining to make them efficient.

[1] The terms OpenVMS and VMS refer to the OpenVMS operating system.

DXML contains the 15 standard BLAS Level 1 operations:

- The index of the element of a vector having maximum absolute value
- The sum of the absolute values of the elements of a vector
- Inner product of two real vectors
- Scalar plus the extended precision inner product of two real vectors
- Conjugated inner product of two complex vectors
- Unconjugated inner product of two complex vectors
- Square root of the sum of squares (norm) of the elements of a vector
- Scalar times a vector plus a vector
- Copy one vector to another
- Apply a Givens rotation
- Apply a modified Givens plane rotation
- Generate elements for a Givens plane rotation
- Generate elements for a modified Givens plane rotation
- Product of a vector times a scalar
- Swap the elements of two vectors

BLAS Level 1 Extensions (Vector/Vector Operations)

When developing mathematical algorithms using the BLAS Level 1, scientists and engineers found that several additional constructs were used on a regular basis. These constructs have also become well known throughout the computer industry and are known as BLAS Level 1 extensions.

DXML contains 13 BLAS Level 1 extension operations:

- Index of element having the minimum absolute value
- Index of element having the maximum value
- Index of element having the minimum value
- Largest value of the elements of a vector
- Smallest value of the elements of a vector
- Largest absolute value of the elements of a vector
- Smallest absolute value of the elements of a vector
- Sum of the values of the elements of a vector
- Set all elements of a vector equal to a scalar
- Constant times a vector set to another vector (y = a*x)
- Euclidean norm with no intermediate scaling
- Sum of the squares of the elements of a vector
- Constant times a vector plus a vector set to another vector (z = a*x + y)

BLAS Level 1 Sparse Extensions (Vector/Vector Operations)

This group of operations is similar to the BLAS Level 1 routines, but is designed to work on sparse vectors (vectors in which most of the elements are zero). Six of the routines are equivalent to the dense Level 1 routines, but are modified to work on vectors stored in a compressed form. Three additional routines are added for convenience.

BLAS Level 2 (Matrix/Vector Operations)

The BLAS Level 2 codes make more effective utilization of the data in the vector registers, reducing the number of vector loads and stores required. In addition, loop unrolling techniques are used to minimize cache misses and page faults. The BLAS Level 2 subroutines use the following types of operations:

- Matrix/vector products
- Rank-1 and rank-2 matrix updates
- Solutions of triangular systems of equations

Six types of matrices are supported by these BLAS Level 2 routines:

- General
- General Band
- Symmetric/Hermitian
- Symmetric/Hermitian Band
- Triangular
- Triangular Band

BLAS Level 3 (Matrix/Matrix Operations)

The BLAS Level 3 routines operate at a level that makes the most efficient use of machine resources. DXML optimizes these routines by partitioning matrices into blocks and computing matrix/matrix operations on each block. This approach avoids excessive memory accesses by providing full reuse of data while each block is in the cache or the registers. BLAS Level 3 routines provide this kind of blocking for three basic types of operations:

- Matrix/matrix products
- Rank-k and rank-2k updates of a symmetric matrix
- Solving triangular systems of equations with multiple right-hand sides

Three types of matrices are supported by these BLAS Level 3 routines:

- General
- Symmetric/Hermitian

- Triangular

BLAS Level 3 Extensions

A set of additional matrix-matrix routines are provided for convenience. The three extensions provided are:

- Add two matrices
- Subtract one matrix from another
- Transpose a matrix, in-place or out-of-place

LAPACK Library Contents

LAPACK is a library of linear algebra subroutines intended to solve a wide range of problems in linear algebra. LAPACK can be used to solve dense systems of linear equations, linear least squares problems, eigenvalue problems, and singular value problems. It is also useful in doing other computations such as matrix factorizations and estimations of condition numbers.

The DXML LAPACK Library provides the complete LAPACK package. DXML's version of LAPACK is provided as a shareable image, compiled, tested, and ready-to-use. Combined with the optimized BLAS Level 3 routines, the DXML LAPACK will provide optimal performance on all supported platforms. LAPACK should be used in place of LINPACK and EISPACK, since it is more efficient, accurate, and robust than those older packages.

LAPACK supports both real and complex, single and double precision data. It operates on the following types of matrices:

- Bidiagonal
- General band
- General unsymmetric
- General tridiagonal
- Hermitian
- Hermitian, packed storage
- Upper Hessenberg, generalized problem
- Upper Hessenberg
- Orthogonal
- Orthogonal, packed storage
- Symmetric/Hermitian positive definite band
- Symmetric/Hermitian positive definite
- Symmetric/Hermitian positive definite, packed storage
- Symmetric/Hermitian positive definite tridiagonal
- Symmetric band
- Symmetric, packed storage
- Symmetric tridiagonal
- Symmetric
- Triangular band
- Triangular, generalized problem
- Triangular, packed storage
- Triangular
- Trapezoidal
- Unitary
- Unitary, packed storage

LAPACK provides the following operations:

- Triangular factorization
- Unblocked triangular factorization
- Solve a system of linear equations (based on triangular factorization)
- Compute the inverse (based on triangular factorization)
- Unblocked computation of inverse
- Estimate condition number
- Refine initial solution returned by solver
- Perform QR factorization without pivoting
- Unblocked QR factorization
- Solve linear least squares problem (based on QR factorization)
- Perform LQ factorization without pivoting
- Unblocked LQ factorization
- Solve underdetermined linear system (based on LQ factorization)
- Generate a real orthogonal or complex unitary matrix as a product of Householder matrices
- Unblocked generation of real orthogonal or unitary matrix
- Multiply a matrix by a real orthogonal or complex unitary matrix by applying a product of Householder matrices
- Unblocked version of above multiply
- Reduce a square matrix to upper Hessenberg form
- Unblocked version of square matrix reduction
- Reduce a symmetric matrix to real symmetric tridiagonal form
- Unblocked version of symmetric matrix reduction
- Reduce a rectangular matrix to bidiagonal form
- Compute eigenvalues and optional Schur factorization or eigenvectors using QR algorithm

- Compute selected eigenvectors by inverse iteration
- Compute eigenvectors from Schur factorization
- Compute eigenvectors using the Pal-Walker-Kahan variant of the QL or QR algorithm
- Compute singular values and, optionally, singular vectors using the QR algorithm

Sparse System Solver Library Contents

The DXML Sparse System Solver Library contains a set of subroutines that may be used to solve sparse linear systems of equations. The library contains a set of storage methods, preconditioners, and iterative solvers.

Routines for three storage methods are provided, or the user may develop routines to employ a custom storage scheme. The supplied storage schemes include:

- Symmetric diagonal
- Unsymmetric diagonal
- General storage by rows

Three preconditioners are supplied, which can be selectively applied to the data. Users may also supply custom preconditioners. The preconditioners supplied include:

- Diagonal
- Polynomial (Neumann)
- Incomplete LU with zero diagonals added

Five iterative sparse solvers for real, double precision data are supplied:

- Preconditioned conjugate gradient method
- Preconditioned least squares conjugate gradient method
- Preconditioned bi-conjugate method
- Preconditioned conjugate gradient squared method
- Preconditioned generalized minimum residual method

Signal Processing Library Contents

The DXML Signal Processing Library contains a set of subroutines in three basic areas of signal processing:

- Fast Fourier Transforms
- Convolution and Correlation
- Digital Filters

Fast Fourier Transforms (FFTs)

DXML provides one-dimensional, two-dimensional, three-dimensional, and group FFT routines. Each routine is supplied in two forms:

- The first form computes the transform in one unit operation. This is convenient for programs requiring speed on only one or a few FFT operations.
- The second form is provided for programs requiring speed on repeated FFT operations. With this form, each routine is subdivided into three routines. One routine builds the rotation factors, a second routine applies them to the data to perform the FFT, and a third routine deallocates any virtual memory allocated in the first routine. Thus, for repeated operations, the rotation factors need to be built only once.

Convolution and Correlation

DXML provides routines for computing one-dimensional discrete convolutions and correlations. These routines can process both periodic and nonperiodic data.

Digital Filters

DXML provides support for one-dimensional, nonrecursive digital filtering. Based on the Kaisers Sinh-Bessel algorithm, these routines allow programming of bandpass, bandstop, low-pass, and high-pass filters.

DXML Run-Time Only License

The Digital Extended Math Library is an application development tool that provides convenience and improved performance to the developer. To encourage application developers to incorporate DXML routines into their applications for distribution to other users, Digital provides a DXML Run-Time Only license to allow running applications that call DXML routines. This license is offered at a substantially reduced price. The DXML Run-Time License does not allow new applications to be developed, but does allow applications developed on another system with the Development License to be run.

HARDWARE REQUIREMENTS

Processor and/or hardware configurations as specified in the System Support Addendum (SSA 31.67.01-x).

SOFTWARE REQUIREMENTS

For Systems Using Terminals (No DECwindows Interface):

OpenVMS Operating System

For Workstations Running VWS:

OpenVMS Operating System

OpenVMS Workstation Software

Refer to the System Support Addendum (SSA 31.67.01-x) for availability and required versions of prerequisite /optional software.

ORDERING INFORMATION

Development Option

Software Licenses: QL-YEZ99-J*
Software Media: QA-YEZAA-**
Software Documentation: QA-YEZAA-GZ
Software Product Services: QT-YEZA*-**

Run-Time Option

Software Licenses: QL-MUS99-J*
Software Media: QA-MUSAA-**
Software Product Services: QT-MUSA*-**

* Denotes variant fields. For additional information on available licenses, services, and media, refer to the appropriate price book.

SOFTWARE LICENSING

This software is furnished under the licensing provisions of Digital Equipment Corporation's Standard Terms and Conditions. For more information about Digital's licensing terms and policies, contact your local Digital office.

License Management Facility Support:

This layered product supports the OpenVMS License Management Facility. License units for this product are allocated on an Unlimited Use Basis.

For more information on the License Management Facility, refer to the OpenVMS Operating System Software Product Description (SPD 25.01.xx) or the *License Management Facility* manual of the OpenVMS Operating System documentation set.

For more information about Digital's licensing terms and policies, contact your local Digital office.

SOFTWARE PRODUCT SERVICES

A variety of service options are available. For more information, please contact your local Digital office.

SOFTWARE WARRANTY

Warranty for this software product is provided by Digital with the purchase of a license for the product as defined in the Software Warranty Addendum.

™ The DIGITAL Logo, CI, DEC, DECwindows, Digital, MicroVAX, OpenVMS, TK, VAX, VAXcluster, VAXft, VAXserver, VAXstation, and VMS are trademarks of Digital Equipment Corporation.