Intel® Math Kernel Library (Intel® MKL)
Intel® Math Kernel Library (Intel® MKL) Introduction

Highly optimized threaded math routines
- Performance, Performance, Performance!

Industry’s leading math library
- Widely used in science, engineering, data processing

Tuned for Intel® processors – current and next generation

Intel Engineering
Algorithm Experts
Optimized code path dispatch auto

Intel® Compatible Processors
Past Intel® Processors
Current Intel® Processors
Future Intel® Processors

More math library users depend on MKL than any other library

Be multiprocessor aware
- Cross-Platform Support
- Be vectorised, threaded, and distributed multiprocessor aware
Intel MKL unleashes the performance benefits of Intel architectures

DGEMM Performance Boost by using Intel® MKL vs. ATLAS*

Configuration Info - Versions: Intel® Math Kernel Library (Intel® MKL) 11.3, ATLAS* 3.10.2; Hardware: Intel® Xeon® Processor E5-2699 v3, 2 Eighteen-core CPUs (45MB LLC, 2.3GHz), 64GB of RAM; Intel® Core™ Processor i7-4770K, Quad-core CPU (8MB LLC, 3.5GHz), 8GB of RAM; Operating System: RHEL 6.4 x86_64; Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. * Other brands and names are the property of their respective owners. Benchmark Source: Intel Corporation

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## Optimized Mathematical Building Blocks

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<th>Fast Fourier Transforms</th>
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<th>Vector RNGs</th>
<th>Summary Statistics</th>
<th>Deep Neural Networks (DNN)</th>
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<td>• Sparse Solvers</td>
<td>• Iterative</td>
<td>• Log</td>
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<td>• Iterative</td>
<td>• Cluster FFT</td>
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</tr>
<tr>
<td>• PARDISO* SMP &amp; Cluster</td>
<td></td>
<td>• Root</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Optimization Notice

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BLAS – Basic Linear Algebra Subprograms

Defacto-standard APIs since the 1980s (Fortran 77)

- Level 1 – vector-vector operations
- Level 2 – matrix-vector operations
- Level 3 – matrix-matrix operations
- Precisions: single, double, single complex, double complex

Original BLAS available at http://netlib.org/blas/

<table>
<thead>
<tr>
<th>Operation</th>
<th>MKL Routine “D is for double”</th>
<th>Example</th>
<th>Computational complexity (work)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector Vector</td>
<td>D AXPY</td>
<td>y = y + α x</td>
<td>O(N)</td>
</tr>
<tr>
<td>Matrix Vector</td>
<td>D GEMV</td>
<td>y = αAx + βy</td>
<td>O(N²)</td>
</tr>
<tr>
<td>Matrix Matrix</td>
<td>D GEMM</td>
<td>C = αA * B + βC</td>
<td>O(N³)</td>
</tr>
</tbody>
</table>
LAPACK – Linear Algebra PACKage

Defacto-standard APIs since early 1990s
1000s of linear algebra functions
4 floating point precisions supported

Breadth of coverage:
- Matrix factorizations: the 3 Amigos – LU, Cholesky, QR
- Solving systems of linear equations
- Condition number estimates
- Singular value decomposition
- Symmetric and non-symmetric eigenvalue problems
- And much, much more

Original LAPACK is available at:
http://netlib.org/lapack/
Fast Fourier Transform (FFT)

Support multidimensional transforms

Multiple transforms on single call

Input/output strides supported

Allow FFT of a part of image, padding for better performance, transform combined with transposition, facilitates development of mixed-language applications.

Integrated FFTW interfaces

Source code of FFTW3 and FFTW2 wrappers in C/C++ and Fortran are provided.

FFTW3 wrappers are also built into the library.
Vector Math Functions

Example: \( y(i) = e^{x(i)} \) for \( i = 1 \) to \( n \)

- Arithmetic
  - add/sub/sqrt/ ...
- Exponential and log
  - exp/pow/log/log10
- Trigonometric and hyperbolic
  - sin/cos/sincos/tan(h)
  - asin/acos/atan(h)
- Rounding
  - ceil, floor, round ...
- And many more ...

- Real and complex
- Single/double precision
- 3 accuracy modes
  - High accuracy
    - (Almost correctly rounded)
  - Low accuracy
    - (2 lowest bits in error)
  - Enhanced performance
    - (1/2 the bits correct)

*Vector-based elementary functions allow developers to balance accuracy with performance*
## Vector Statistics

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Random Number Generators (RNGs)</strong></td>
<td>Psuedo-random, quasi-random, and non-deterministic generators</td>
</tr>
<tr>
<td></td>
<td>Continuous and discrete distributions of various common distribution types</td>
</tr>
<tr>
<td><strong>Summary Statistics (SS)</strong></td>
<td>Parallelized algorithms for computation of statistical estimates for raw multi-dimensional datasets.</td>
</tr>
<tr>
<td><strong>Convolution/correlation</strong></td>
<td>A set of routines intended to perform linear convolution and correlation transformations for single and double precision real and complex data.</td>
</tr>
</tbody>
</table>
## Intel® MKL Sparse Solvers

<table>
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<tr>
<th>Solver</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PARDISO</strong> — Parallel Direct Sparse Solver</td>
<td>Support a wide range of matrix types.</td>
</tr>
<tr>
<td></td>
<td>Based on BLAS level 3 update and pipelining parallelism.</td>
</tr>
<tr>
<td></td>
<td>Supports out-of-core execution for huge problem sizes.</td>
</tr>
<tr>
<td></td>
<td>New: Cluster support.</td>
</tr>
<tr>
<td><strong>DSS</strong> — Direct Sparse Solver Interface for PARDISO</td>
<td>An alternative, simplified interface to PARDISO.</td>
</tr>
<tr>
<td><strong>ISS</strong> — Iterative Sparse Solver</td>
<td>Symmetric positive definite: CG solver.</td>
</tr>
<tr>
<td></td>
<td>Non-symmetric indefinite: Flexible generalized minimal residual solver.</td>
</tr>
<tr>
<td></td>
<td>Based on Reverse Communication Interface (RCI).</td>
</tr>
</tbody>
</table>
More Intel® MKL Components

Data Fitting

1D linear, quadratic, cubic, step-wise const, and user-defined splines
Spline based interpolation/extrapolation

PDEs (Partial Differential Equations)

Solving Helmholtz, Poisson, and Laplace problems.

Optimization Solvers

Solvers for nonlinear least square problems with/without constraints

Support Functions

Memory management
Threading control
…
What are Intel MKL DNN Primitives?

A set of performance primitives to speed up image recognition topologies on existing or custom NN frameworks

- **Topologies**: AlexNet, VGG, GoogleNet, ResNet
- **Frameworks**: Caffe*, TensorFlow*, CNTK*, Torch*, MXNet*, ......

<table>
<thead>
<tr>
<th>Operations (forward/backward)</th>
<th>Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activation</td>
<td>ReLU</td>
</tr>
<tr>
<td>Normalization</td>
<td>batch, local response</td>
</tr>
<tr>
<td>Pooling</td>
<td>max, min, average</td>
</tr>
<tr>
<td>Convolutional</td>
<td>fully connected, direct batched convolution</td>
</tr>
<tr>
<td>Inner product</td>
<td>forward/backward propagation of inner product computation</td>
</tr>
<tr>
<td>Data manipulation</td>
<td>layout conversion, split, concat, sum, scale</td>
</tr>
</tbody>
</table>
DNN Primitives in Intel® MKL Highlights

A plain C API to be used in the existing DNN frameworks

Brings IA-optimized performance to popular image recognition topologies:

- AlexNet, Visual Geometry Group (VGG), GoogleNet, and ResNet

**Caffe/AlexNet single node training performance**

- Intel® Xeon® E5-2699 v4: 5.8x
- Intel® Xeon® E5-2699 v4 + Intel® MKL 11.3.3: 2.1x
- Intel® Xeon® E5-2699 v4 + Intel® MKL 2017: 2x
- Intel® Xeon Phi 7250 + Intel® MKL 2017: 24x

**Caffe/AlexNet single node inference performance**

- Intel Xeon E5-2699v4: 7.5x
- Intel® Xeon® E5-2699v4 + Intel® MKL 11.3.3: 2.2x
- Intel® Xeon® E5-2699v4 + Intel® MKL 2017: 1.9x
- Intel® Xeon Phi 7250 + Intel® MKL 2017: 31x
What’s New: Intel® MKL 2017

- Optimized math functions to enable neural networks (CNN and DNN) for deep learning
- Improved ScaLAPACK performance for symmetric eigensolvers on HPC clusters
- New data fitting functions based on B-splines and monotonic splines
- Improved optimizations for newer Intel processors, especially Knight’s Landing Xeon Phi
- Extended TBB threading layer support for all BLAS level-1 functions
Intel® MKL Summary

Intel MKL boosts application performance with minimal effort

- feature set is robust and growing
- provides scaling from the core, to multicore, to manycore, and to clusters
- automatic dispatching matches the executed code to the underlying processor
- future processor optimizations included well before processors ship

Showcases the world’s fastest supercomputers\(^1\)

- Intel® Optimized MP LINPACK Benchmark
- Intel® Optimized Technology Preview for High Performance Conjugate Gradient Benchmark

\(^1\)http://www.top500.org
Intel® Integrated Performance Primitives (Intel® IPP)
Intel® IPP Your Building Blocks for Image, Signal & Data Processing Applications

What is Intel® IPP?
Intel IPP provides developers with ready-to-use, processor optimized functions to accelerate *Image, Signal, Data Processing & Cryptography computation tasks.*

Why should you use Intel® IPP?
- High Performance
- Easy to use API’s
- Faster Time To Market (TTM)
- Production Ready

How to get Intel® IPP?
Intel Parallel Studio XE
Intel System Studio
Free Tools Program

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Find out more at: [http://software.intel.com/intel-ipp](http://software.intel.com/intel-ipp)
Contact us through our forum:
Different Domains in Intel IPP

Image Domain
- Image Processing
- Computer Vision
- Color Conversion

Signal Domain
- Signal Processing
- Vector Math

Data Domain
- Data Compression
- Cryptography
- String Processing
### Filters/Transforms for Image processing

- Geometry transformations, such as resize/rotate.
- Linear and non-linear filtering operation on an image for edge detection, blurring, noise removal, etc.
- Linear transforms for 2D FFTs, DFTs, DCT.
- Image statistics and analysis.

### Computer Vision

- Background differencing, Feature Detection (Corner Detection, Canny Edge detection), Distance Transforms.
- Image Gradients, Flood fill, Motion analysis and Object Tracking,
- Pyramids, Pattern recognition, Camera Calibration
- Canny, Optical Flow, Segmentation, Haar Classifiers

### Color Conversion

- Convert image/video color space formats: RGB, HSV, YUV, YCbCr
- Up/Down sampling,
- Brightness and contrast adjustments
IPP Image Processing Function Sets

Ready to use high performance Image processing functions (2D):

- Memory allocation and image initialization
- Arithmetic and logical operations
- Color conversion
- Compare and threshold
- Morphological operations
- Filtering
- Linear transforms
- Geometry transforms
- Image statistical functions

More than two thousands functions for processing different format images
Intel® IPP Image Resize Functions Performance Boost

Intel® IPP AVX2 Optimization Code vs. Compiled C Code

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Intel® IPP Image Resize Functions Performance Boost
Intel® IPP AVX-512 Optimization Code vs. Compiled C Code

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Configuration Info: SW Versions: Intel® Integrated Performance Primitives (Intel® IPP) 2017, RHEL Server 7.0, 64-bit. Hardware: Intel® Xeon Phi™ Processor 7250, 32 MB L2 cache, 1.4 GHz. Single-threaded. Compiler: Intel® C Compiler 16.0, with -O3, -DMIC-AVX512 options. Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any changes to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. * Other brands and names are the property of their respective owners. Benchmark Source: Intel Corporation.
## Ready to use high performance Signal processing functions (1D)

### Signal Processing
- FFT, DFT, DCT, MDCT
- Wavelet, Hilbert, Hartley and Walsh-Hadamard Transforms
- Convolution, Cross-Correlation, Auto-Correlation, Conjugate
- Windowing, Jaehne/Tone/Triangle signal generation

### Digital Filtering
- Finite Impulse Response (FIR), Infinite Impulse Response (IIR), Single-Rate Adaptive FIR, Multi-Rate Adaptive FIR, Median Filter, Convolution and Correlation,
- Coordinate Conversions (polar↔cartesian), Numeric Conversion (real↔complex), Emphasize, Nearest Neighbor, Threshold

### Statistics
- Mean
- StdDev
- NormDiff
- Sum
- MinMax
Intel® IPP Signal Processing Functions Performance Boost
Intel® IPP AVX2 Optimization Code vs. Compiled C Code

Compiler: Intel C++ Compiler 16.0, with -O3--AVX2 options.
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Intel® IPP AVX-512 Optimization Code vs. Compiled C Code

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## Intel® IPP Data Processing

### Data Compression
- Huffman/Variable Length Coding (VLC)
- Lempel-Ziv-Storer-Syzmanski (LZSS) PKzip
- Lempel-Ziv (lz77) Zlib, gzip
- Lempel-Ziv-Oberhumer (LZO) IZop
- Burrows-Wheeler Transform (BWT) bzip2

### Cryptography
- Symmetric cryptography (AES, TDES)
- One-way hash (SHA1, MD5)
- Public key cryptography (RSA)

### String Processing
- Find
- Insert
- Remove
- Compar
- Trim
- Replace
- Upper, Lower
- Hash
- Concatenate, Split
- Regular Expression Find/Replace
Intel® IPP Data Compression and Decompression Performance Boost vs. ZLIB Library

<table>
<thead>
<tr>
<th></th>
<th>zlib 1.2.8</th>
<th>Intel® IPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression (Level=1)</td>
<td>1</td>
<td>1.3x</td>
</tr>
<tr>
<td>Compression (Level=6)</td>
<td>1</td>
<td>2.1x</td>
</tr>
<tr>
<td>Compression (Level=9)</td>
<td>1</td>
<td>2.7x</td>
</tr>
<tr>
<td>Compression (Level=IPP Fastest*)</td>
<td>1</td>
<td>3.3x</td>
</tr>
<tr>
<td>Decompression</td>
<td>1</td>
<td>1.9x</td>
</tr>
</tbody>
</table>

Configuration info—SW Versions: Intel® Integrated Performance Primitives (Intel® IPP) 2017, Intel C++ Compiler 16.0. Hardware: Intel® Core™ Processor i7-6700K, 8 MB cache, 4.2 GHz, 16 GB RAM, Windows Server® 2012 R2. Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. * Other brands and names are the property of their respective owners. Benchmark Source: Intel Corporation

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Intel® IPP MD5 Performance Boost
Intel® AVX2 Optimization Code vs. Intel® IPP C optimized code

<table>
<thead>
<tr>
<th>Length</th>
<th>Intel® IPP C compiled code (PX) code</th>
<th>Intel® AVX2</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>128</td>
<td>1</td>
<td>1.19</td>
</tr>
<tr>
<td>256</td>
<td>1</td>
<td>1.18</td>
</tr>
<tr>
<td>1024</td>
<td>1</td>
<td>1.22</td>
</tr>
</tbody>
</table>


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## Code Dispatching

- Intel IPP functions are optimized for specific processors.
- A single function has many versions, each one optimized to run on a specific processor.
- New CPU dispatching code K0 for processors with Intel® Advanced Vector Extensions 512 (Intel® AVX-512).

### Optimization Notice

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### Some examples:

- `ippsCopy_8u(…)`
- `mx_ippsCopy_8u(…)`
- `i9_ippsCopy_8u(…)`
- `k0_ippsCopy_8u(…)`

### Table of Platforms and Identifiers

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<thead>
<tr>
<th>Platform</th>
<th>Identifier</th>
<th>Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA-32 Intel® Architecture</td>
<td>px</td>
<td>C-optimized for all IA-32 processors</td>
</tr>
<tr>
<td></td>
<td>w7</td>
<td>Optimized for processors with Intel SSE2</td>
</tr>
<tr>
<td></td>
<td>p8</td>
<td>Optimized for processors with Intel® Streaming SIMD Extensions 4.1 (Intel SSE4.1)</td>
</tr>
<tr>
<td></td>
<td>h9</td>
<td>Optimized for processors with Intel® Advanced Vector Extensions 2 (Intel® AVX2)</td>
</tr>
<tr>
<td>Intel® 64 architecture</td>
<td>mx</td>
<td>C-optimized for processors with Intel® 64 instructions set architecture</td>
</tr>
<tr>
<td></td>
<td>n8</td>
<td>Optimized for the Intel® Atom™ processor</td>
</tr>
<tr>
<td></td>
<td>y8</td>
<td>Optimized for 64-bit applications on processors with Intel® Streaming SIMD Extensions 4.1 (Intel SSE4.1)</td>
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<tr>
<td></td>
<td>e9</td>
<td>Optimized for processors that support Intel® Advanced Vector Extensions instruction set</td>
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<tr>
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<td>l9</td>
<td>Optimized for processors with Intel® Advanced Vector Extensions 2 (Intel® AVX2)</td>
</tr>
<tr>
<td></td>
<td>k0</td>
<td>Optimized for processors with Intel® Advanced Vector Extensions 512 (Intel® AVX-512)</td>
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## Intel® IPP Linkage

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<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Optimization</strong></td>
<td>All processors</td>
<td>All processors</td>
<td>All processors</td>
<td>One processor</td>
</tr>
<tr>
<td><strong>Build</strong></td>
<td>Link to stub libraries</td>
<td>Link to static libraries and stubs</td>
<td>Build separate DLL</td>
<td>Link to processor-specific merged libraries</td>
</tr>
<tr>
<td><strong>Calling</strong></td>
<td>Regular names</td>
<td>Regular names</td>
<td>Modified names</td>
<td>Processor-specific names</td>
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<td><strong>Total Binary Size</strong></td>
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<td>Small</td>
<td>Smallest</td>
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<tr>
<td><strong>Executable Size</strong></td>
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<tr>
<td><strong>Kernel Mode</strong></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Intel® IPP provides a lot of flexibility**
New Enhancements in Intel® IPP 2017

• New zlib example to provide drop-in optimization of zlib library with Intel® IPP functions.
  - Provided additional optimization on pattern matching algorithms.
  - Added a new fastest compression level with best compression performance.

• Added Intel® IPP Platform-Aware APIs to support 64-bit parameters:
  - New 64-bit parameters can support large image and vector data processing.
  - Support external tiling and threading by processing tiled images, and enables application level threading.

• New C and C++ integration wrappers for the image processing and computer vision functions.

• New performance improvement and optimization:
  - Support for recently launched versions of Intel® processors, including Intel® Xeon Phi™ processor x200 (formerly code-named Knights Landing).
  - Extended Intel® SSE4.2, Intel® AVX-512 and Intel® AVX2 optimization.
Intel® Data Analytics Acceleration Library (Intel® DAAL)
Data Analytics in the Age of Big Data

Problem:

- Big data needs high performance computing.
- Many big data applications leave performance at the table – Not optimized for underlying hardware.

Solution:

- A performance library provides building blocks to be easily integrated into big data analytics workflow.
Intel® Data Analytics Acceleration Library (Intel® DAAL)

An Intel-optimized library that provides building blocks for all data analytics stages, from data preparation to data mining & machine learning

- Python, Java & C++ APIs
- Can be used with many platforms (Hadoop*, Spark*, R*, …) but not tied to any of them
- Flexible interface to connect to different data sources (CSV, SQL, HDFS, …)
- Windows*, Linux*, and OS X*

- Developed by same team as the industry-leading Intel® Math Kernel Library
- Open source, Free community-supported and commercial premium-supported options
- Also included in Parallel Studio XE suites
Intel® Data Analytics Acceleration Library
(Intel® DAAL)

An industry leading Intel® Architecture based data analytics acceleration library of fundamental algorithms covering all machine learning stages.

Scientific/Engineering
Web/Social
Business

Pre-processing
Transformation
Analysis
Modeling
Validation
Decision Making

(De-)Compression
Outlier Detection
Normalization

PCA
Statistical moments
Variance matrix
Pp-QR, SVD, Cholesky
Apriori
Sorting

Ridge linear regression
Naïve Bayes
SVM
Classifier boosting
Kmeans
EM GMM

Collaborative filtering
Neural Networks
Intel DAAL Performance Scaling

Within a CPU core:
- SIMD vectorization: optimized for the latest instruction sets, AVX2, AVX512...
- Internally relies on sequential MKL

Scale to multi cores or many cores:
- Intel TBB threading

Scale to cluster:
- Distributed processing done by user application (MPI, MapReduce, etc.)
- DAAL provides
  - Data structures for partial and intermediate results
  - Functions to combine partial or intermediate results into global result
<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Batch</th>
<th>Distributed</th>
<th>Online</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive statistics</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Low order moments</td>
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<td>√</td>
<td>√</td>
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<tr>
<td>Quantiles/sorting</td>
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<tr>
<td><strong>Statistical relationships</strong></td>
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<tr>
<td>Correlation / Variance-Covariance</td>
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<td>√</td>
<td>√</td>
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<tr>
<td>(Cosine, Correlation) distance matrices</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Matrix decomposition</strong></td>
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<td></td>
</tr>
<tr>
<td>SVD</td>
<td>√</td>
<td>√</td>
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<tr>
<td>Cholesky</td>
<td>√</td>
<td></td>
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</tr>
<tr>
<td>QR</td>
<td>√</td>
<td>√</td>
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<td><strong>Regression</strong></td>
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<tr>
<td>Linear/ridge regression</td>
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<td>√</td>
<td>√</td>
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<tr>
<td><strong>Classification</strong></td>
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<tr>
<td>Multinomial Naïve Bayes</td>
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<td>√</td>
<td>√</td>
</tr>
<tr>
<td>SVM (two-class and multi-class)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Boosting (Ada, Brown, Logit)</td>
<td>√</td>
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<tr>
<td><strong>Unsupervised learning</strong></td>
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<tr>
<td>Association rules mining (Apriori)</td>
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</tr>
<tr>
<td>Anomaly detection (uni-/multi-variate)</td>
<td>√</td>
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<tr>
<td>PCA</td>
<td>√</td>
<td>√</td>
<td>√</td>
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<tr>
<td>KMeans</td>
<td>√</td>
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<tr>
<td>EM for GMM</td>
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<tr>
<td><strong>Recommender systems</strong></td>
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<td></td>
</tr>
<tr>
<td>ALS</td>
<td>√</td>
<td></td>
<td>√</td>
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<tr>
<td><strong>Deep learning</strong></td>
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<tr>
<td>Fully connected, convolution,</td>
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<tr>
<td>normalization, activation layers,</td>
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</tr>
<tr>
<td>model, NN, optimization solvers,</td>
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<td></td>
<td></td>
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<tr>
<td>√</td>
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</tr>
</tbody>
</table>
Processing modes

Batch Processing

$$R = F(D_1, \ldots, D_k)$$

Online Processing

$$S_{i+1} = T(S_i, D_i)$$
$$R_{i+1} = F(S_{i+1})$$

Distributed Processing

$$R = F(R_1, \ldots, R_k)$$
**Intel® DAAL vs. Spark® Mllib**

**K-means Performance Comparison on Eight-node Cluster**

![Graph showing speedup comparison between Intel DAAL and Spark Mllib](image)

**Configuration Info:**
- Versions: Intel® Data Analytics Acceleration Library 2017, Spark 1.2
- Hardware: Intel® Xeon® Processor E5-2699 v3, 2 Eighteen-core CPUs (45MB LLC, 2.3GHz), 128GB of RAM per node
- Operating System: CentOS 6.6 x86_64

Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. *Other brands and names are the property of their respective owners.* Benchmark Source: Intel Corporation

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Intel® DAAL Performance

PCA Performance Boosts
Using Intel® DAAL vs. Spark* MLlib on an Eight-node Cluster

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Speedup</th>
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<tbody>
<tr>
<td>1M rows, 200 columns</td>
<td>3.4x</td>
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<tr>
<td>1M rows, 400 columns</td>
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<tr>
<td>1M rows, 600 columns</td>
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<tr>
<td>1M rows, 800 columns</td>
<td>5.4x</td>
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<tr>
<td>1M rows, 1K columns</td>
<td>6.4x</td>
</tr>
<tr>
<td>10M rows, 5K columns</td>
<td>11.5x</td>
</tr>
<tr>
<td>20M rows, 5K columns</td>
<td>11.6x</td>
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<tr>
<td>40M rows, 5K columns</td>
<td>10.2x</td>
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</tbody>
</table>

Configuration Info - Versions: Intel® Data Analytics Acceleration Library 2017, Spark 1.2; Hardware: Intel® Xeon® Processor E5-2699 v3, 2 Eighteen-core CPUs (45MB LLC, 2.3GHz), 128GB of RAM per node; Operating System: CentOS 6.6 x86_64.

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Demo: Handwritten Digit Recognition
Handwritten Digit Recognition

Training multi-class SVM for 10 digits recognition.

3,823 pre-processed training data.

- available at

99.6% accuracy with 1,797 test data from the same data provider.

Confusion matrix:

```
177.000 0.000 0.000 0.000 1.000 0.000 0.000 0.000 0.000 0.000
0.000 181.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 1.000
0.000 2.000 173.000 0.000 0.000 0.000 0.000 1.000 1.000 0.000
0.000 0.000 0.000 176.000 0.000 1.000 0.000 0.000 0.000 3.000
0.000 1.000 0.000 0.000 179.000 0.000 0.000 0.000 1.000 0.000
0.000 0.000 0.000 0.000 180.000 0.000 0.000 0.000 0.000 2.000
0.000 0.000 0.000 0.000 180.000 0.000 1.000 0.000 1.000 0.000
0.000 0.000 0.000 0.000 0.000 170.000 1.000 8.000 0.000 0.000
0.000 3.000 0.000 0.000 0.000 0.000 2.000 0.000 166.000 5.000
0.000 0.000 0.000 2.000 0.000 1.000 0.000 0.000 2.000 175.000
```

Average accuracy: 0.996
Error rate:     0.004
Micro precision: 0.978
Micro recall:   0.978
Micro F-score:  0.978
Macro precision: 0.978
Macro recall:   0.978
Macro F-score:  0.978
void trainModel()
{
    /* Initialize FileDataSource<CSVFeatureManager> to retrieve input data from .csv file */
    FileDataSource<CSVFeatureManager> trainDataSource(trainDatasetFileName,
        DataSource::doAllocateNumericTable, DataSource::doDictionaryFromContext);

    /* Load data from the data files */
    trainDataSource.loadDataBlock(nTrainObservations);

    /* Create algorithm object for multi-class SVM training */
    multi_class_classifier::training::Batch<> algorithm;

    algorithm.parameter.nClasses = nClasses;
    algorithm.parameter.training = training;

    /* Pass training dataset and dependent values to the algorithm */
    algorithm.input.set(classifier::training::data, trainDataSource.getNumericTable());

    /* Build multi-class SVM model */
    algorithm.compute();

    /* Retrieve algorithm results */
    trainingResult = algorithm.getResult();

    /* Serialize the learned model into a disk file */
    ModelFileWriter writer("./model");
    writer.serializeToFile(trainingResult->get(classifier::training::model));
}
void testDigit()
{
    /* Initialize FileDataSource<CSVFeatureManager> to retrieve the test data
    from .csv file */
    FileDataSource<CSVFeatureManager> testDataSource(testDatasetFileName,
        DataSource::doAllocateNumericTable, DataSource::doDictionaryFromContext);
    testDataSource.loadDataBlock(1);

    /* Create algorithm object for prediction of multi-class SVM values */
    multi_class_classifier::prediction::Batch<> algorithm;
    algorithm.parameter.prediction = prediction;

    /* Deserialized a model from a disk file */
    ModelFileReader reader("./model");
    services::SharedPtr<
        multi_class_classifier::Model> pModel(new
        multi_class_classifier::Model);
    reader.deserializeFromFile(pModel);

    /* Pass testing dataset and trained model to the algorithm */
    algorithm.input.set(classifier::prediction::data,
        testDataSource.getNumericTable());
    algorithm.input.set(classifier::prediction::model, pModel);

    /* Predict multi-class SVM values */
    algorithm.compute();

    /* Retrieve algorithm results */
    predictionResult = algorithm.getResult();

    /* Retrieve predicted labels */
    predictedLabels = predictionResult->get(classifier::prediction::prediction);
}
SVM Performance Boosts Using Intel® DAAL vs. scikit-learn on Intel® CPU

Configuration Info - Versions: Intel® Data Analytics Acceleration Library 2016 U2, scikit-learn 0.16.1; Hardware: Intel Xeon E5-2680 v3 @ 2.50GHz, 24 cores, 30 MB L3 cache per CPU, 256 GB RAM; Operating System: Red Hat Enterprise Linux Server release 6.6, 64-bit.

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Resources

Intel® MKL Product Information

Intel® MKL benchmarks

Intel® IPP Product Information
- https://software.intel.com/software/products/ipp

Intel® DAAL Product Information

Intel® DAAL Getting Started Guides
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