



INTEL[®] MATH KERNEL LIBRARY, BLAS USAGE

Gennady.Fedorov@intel.com

What's Inside Intel® MKL

Accelerate HPC, Enterprise, IoT & Cloud Applications

Linear Algebra

- **BLAS**
- LAPACK
- ScaLAPACK
- Sparse BLAS
- Iterative sparse solvers
- PARDISO*
- Cluster Sparse Solver

FFTs

- Multidimensional
- FFTW interfaces
- Cluster FFT

Neural Networks

- Convolution
- Pooling
- Normalization
- ReLU
- Inner Product

Vector RNGs

- Congruential
- Wichmann-Hill
- Mersenne Twister
- Sobol
- Neiderreiter
- Non-deterministic

Summary Statistics

- Kurtosis
- Variation coefficient
- Order statistics
- Min/max
- Variance-covariance

Vector Math

- Trigonometric
- Hyperbolic
- Exponential
- Log
- Power
- Root

And More

- Splines
- Interpolation
- Trust Region
- Fast Poisson Solver

Intel® Architecture Platforms

Operating System: Windows*, Linux*, MacOS1*



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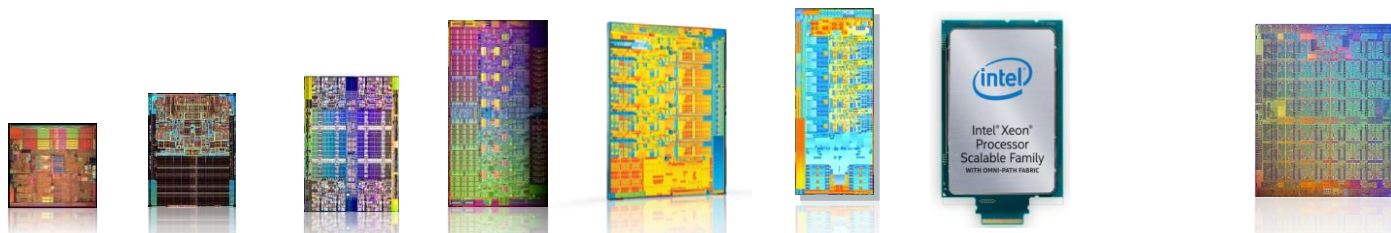
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¹ Available only in Intel® Parallel Studio Composer Edition.



Automatic Dispatching to Tuned ISA-specific Code Paths

More cores → More Threads → Wider vectors



	Intel® Xeon® Processor 64-bit	Intel® Xeon® Processor 5100 series	Intel® Xeon® Processor 5500 series	Intel® Xeon® Processor 5600 series	Intel® Xeon® Processor E5-2600 v2 series	Intel® Xeon® Processor E5-2600 v3 series v4 series	Intel® Xeon® Scalable Processor ¹	Intel® Xeon Phi™ x200 Processor (KNL)
Up to Core(s)	1	2	4	6	12	18-22	28	72
Up to Threads	2	2	8	12	24	36-44	56	288
SIMD Width	128	128	128	128	256	256	512	512
Vector ISA	Intel® SSE3	Intel® SSE3	Intel® SSE4- 4.1	Intel® SSE 4.2	Intel® AVX	Intel® AVX2	Intel® AVX-512	Intel® AVX-512

1. Product specification for launched and shipped products available on ark.intel.com.

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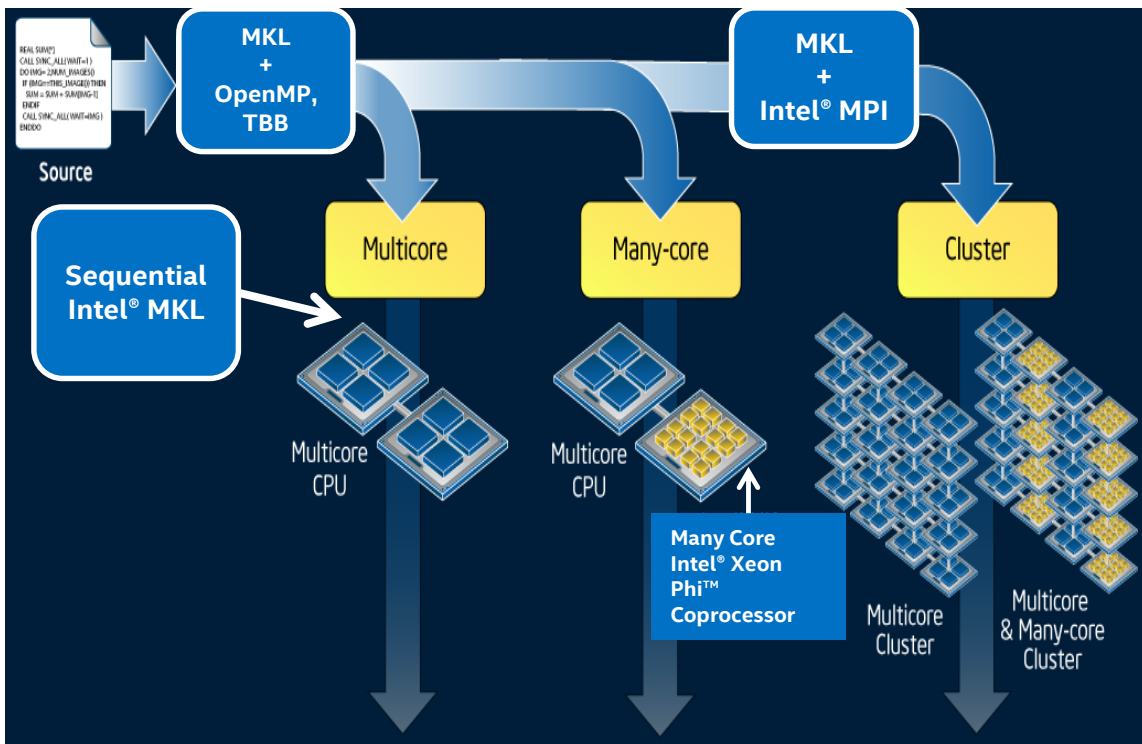


Automatic Performance Scaling from the Core, to Multicore, to Many Core and Beyond

Intel® MKL

Extracting performance from the computing resources

- Core: **vectorization**, prefetching, cache utilization
- Multi-Many core (processor/socket) level **parallelization**
- Multi-socket (node) level **parallelization**
- Clusters **scaling**



Intel® MKL 2018 New Features and Optimizations

Intel® Xeon Phi™ Knights Mill Optimizations	DNN Convolution and Inner Product functions Single Precision Level 3 BLAS, including SGEMM New INT8 and INT16 GEMM functions
BLAS and LAPACK	Compact BLAS and LAPACK functions Direct Call LAPACK Cholesky and QR factorizations LU factorization and Inverse without pivoting Aasen-based factorization and solve functions Bounded Bunch-Kaufman (Rook) pivoting factorizations
FFTs	Verbose Mode Support
Vector Math - 24 New Functions	v?Fmod, v?Remainder v?Powr, v?Exp2, v?Exp10 v?Cospi, v?Sinpi, v?Tanpi, and more

Introduction

- **Objective:**
 - In these activities, you will run Intel® MKL DGEMM based code
 - Learn how to manage the output and performance
- **Requirements:**
 - Intel® Parallel Studio XE 2018 Composer Edition with Intel® C++ Compiler
 - **Linux*** OS supported by Intel® C++ Compiler
 - Recommended to have at least 3rd **generation Intel® Core™ processor** (with Intel® AVX2)
- **Time : 25 min**

Folder **day1/lab2** :

`mkl_test_v1.c`, `mkl_test_v2.c`, `mkl_test_v3.c`

➤ review test: `cat/less mkl_test_v1.c`.

- `mkl_malloc`, `mkl_free`, `dsecnd`,
- `roll_your_own_multiply`,
- `Ddot_Multiply`,
- `Dgemv_multiply`,
- `Dgemm_multiply`

Note – “<https://software.intel.com/en-us/articles/a-simple-example-to-measure-the-performance-of-an-intel-mkl-function>”

GEMM API: $C = \alpha * op(A) * op(B) + \beta * C$

$$C_{m,n} = A_{m,k} * B_{k,n}$$

```
void cblas_dgemm (  
    const CBLAS_LAYOUT Layout, const CBLAS_TRANSPOSE transa, const CBLAS_TRANSPOSE transb,  
    const MKL_INT m, const MKL_INT n, const MKL_INT k,  
    const double alpha, const double *a,  
    const MKL_INT lda, const double *b, const MKL_INT ldb,  
    const double beta, double *c, const MKL_INT ldc );
```


Intel® MKL Lab – BLAS Usage

Activity #1

#Compiling and Linking:

- Set compiler's environment:

source opt/intel/compilers_and_libraries_2018/linux/bin/**compilervars.sh intel64**

- **icc -mkl mkl_test_v1.c -o 1.out**

#MKL Linker Adviser :

<https://software.intel.com/en-us/articles/intel-mkl-link-line-advisor>

Intel® Math Kernel Library (Intel® MKL) Link Line Advisor v4.7 Reset

Select Intel® product:	Intel(R) MKL 2018.0
Select OS:	Linux*
Select usage model of Intel® Xeon Phi™ Coprocessor:	None
Select compiler:	Intel(R) C/C++
Select architecture:	Intel(R) 64
Select dynamic or static linking:	Static
Select interface layer:	32-bit Integer
Select threading layer:	OpenMP threading
Select OpenMP library:	Intel(R) (libiomp5)
Select cluster library:	<input type="checkbox"/> Cluster PARDISO (BLACS required) <input type="checkbox"/> CDFT (BLACS required) <input type="checkbox"/> ScaLAPACK (BLACS required) <input type="checkbox"/> BLACS
Select MPI library:	<Select MPI>
Select the Fortran 95 interfaces:	<input type="checkbox"/> BLAS95 <input type="checkbox"/> LAPACK95
Link with Intel® MKL libraries explicitly:	<input type="checkbox"/>

Use this link line:

```
-Wl,--start-group ${MKLROOT}/lib/intel64/libmkl_intel_lp64.a  
${MKLROOT}/lib/intel64/libmkl_intel_thread.a ${MKLROOT}/lib/intel64/libmkl_core.a  
-Wl,--end-group -liomp5 -lthread -lm -ldl
```

Compiler options:

```
-I${MKLROOT}/include
```

Notes:

#Run and record execution times:

- ./1.out 1000
- ./1.out 2000
- ~~./1.out 4000~~

./1.out 1000

roll_your_own_multiply(). Elapsed time =, sec

Ddot_Multiply(). Elapsed time =, sec

Dgemv_multiply(). Elapsed time =, sec

Dgemm_multiply(). Elapsed time =,sec

Conclusion?

#review test: cat/less **mkl_test_v2.c**

➤ `icc -mkl mkl_test_v2.c -o 2.out`

#SCALABILITY: Run and record execution times

➤ `export MKL_NUM_THREADS=1`

➤ `./2.out 8000` ... Elapsed time =, sec

➤ `export MKL_NUM_THREADS=2`

➤ `./2.out 8000` Elapsed time =, sec

➤ `export MKL_NUM_THREADS=4`

➤ `./2.out 8000`Elapsed time =, sec

Conclusion?

```
mkl_test_v2.c : cblas_dgemm(....);
```

#Verbose Mode:

➤ `export MKL_VERBOSE=1 // 0 by default`

`int mkl_verbose (true/false); // false by default`

➤ **./2.out 8000**

MKL_VERBOSE Intel(R) MKL 2018.0 Update 2 Product build 20180127 for Intel(R) 64 architecture Intel(R) Advanced Vector Extensions 512 (Intel(R) AVX-512) enabled processors, Lnx 2.30GHz lp64 intel_thread

MKL_VERBOSE

DGEMM(N,N,8000,8000,8000,0x7ffbd682890,0x7f6d8a634080,8000,0x7f6d6bdeb080,8000,0x7ffbd682898,0x7f6d4d5a2080,8000) 4.65s CNR:OFF Dyn:1 FastMM:1 TID:0 NThr:4

#IA Dispatching

```
# review test: cat/less mkl_test_v3.c : cblas_dgemm(...);
```

```
#Environment Variable:
```

```
MKL_ENABLE_INSTRUCTIONS == AVX512 | AVX2 | AVX | SSE4_2
```

```
#Runtime function:
```

```
int mkl_enable_instructions (int isa);
```

```
isa == MKL_ENABLE_AVX512 | MKL_ENABLE_AVX2 | MKL_ENABLE_AVX | MKL_ENABLE_SSE4_2
```

#IA Dispatching

mkl_test_v3.c : cblas_dgemm(....);

- `icc -mkl mkl_test_v3.c -o 3.out`
- `export MKL_VERBOSE=1`

#and run and record execution times:

➤ **./3.out 8000**

- `export MKL_ENABLE_INSTRUCTIONS=AVX2` ... Elapsed time =, sec
- `export MKL_ENABLE_INSTRUCTIONS=AVX` ... Elapsed time =, sec
- `export MKL_ENABLE_INSTRUCTIONS=SSE4_2` ... Elapsed time =, sec
- `export MKL_ENABLE_INSTRUCTIONS=AVX512` ... Elapsed time =, sec

#Conditional Numerical Reproducibility - CNR

`mkl_test_v3.c`

`export MKL_ENABLE_INSTRUCTIONS=`

`export MKL_CBWR=VALUE`

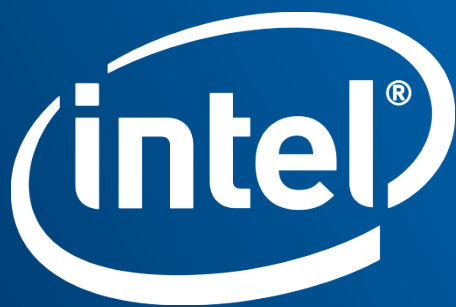
Value	Description
COMPATIBLE	Intel® Streaming SIMD Extensions 2 (Intel® SSE2) without rcp
SSE2	Intel SSE2
SSE3	DEPRECATED. Intel® Streaming SIMD Extensions 3 (Intel® SSE3).
SSSE3	Supplemental Streaming SIMD Extensions 3 (SSSE3)
SSE4_1	Intel® Streaming SIMD Extensions 4-1 (Intel® SSE4-1)
SSE4_2	Intel® Streaming SIMD Extensions 4-2 (Intel® SSE4-2)
AVX	Intel® Advanced Vector Extensions (Intel® AVX)
AVX2	Intel® Advanced Vector Extensions 2 (Intel® AVX2)

#Conditional Numerical Reproducibility - CNR

Run and record execution times

./3.out 8000

- export MKL_CBWR=AVX512 ... Elapsed time =, sec
- export MKL_CBWR=AVX ... Elapsed time =, sec
- export MKL_CBWR=SSE2 ... Elapsed time =, sec
- export MKL_CBWR=COMPATIBLE Elapsed time =, sec



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