
# INTEL® MKL - FAST FOURIER TRANSFORM (FFT)

Gennady Fedorov - Technical Consulting Engineer

Intel Architecture, Graphics and Software (IAGS)

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Gennady.Fedorov@intel.com

# Intel® Math Kernel Library

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

## FFT

## CFFT

## 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

## Benchmarks
- Intel(R) Distribution for LINPACK* Benchmark
- High Performance Computing Linpack Benchmark
- High Performance Conjugate radient Benchmark

Intel® Architecture Platforms


Operating System: Windows*, Linux*, MacOS[1]*

[1] Available only in Intel® Parallel Studio Composer Edition.

# Intel MKL FFT - Agenda

- **Introduction**
- **FFT API**
- **Demo – General Case, Usage Modes**
- **Demo -** 1d-2d case, Batch mode
- **Demo – MKL FFT -** FFTW

# Introduction

- 1, 2 & 3 dimensional (up to the order of 7)
- Multithreaded
- Mixed radix
- Single and double precision complex and real transforms
- Placement of results: in-place, out of place
- Non-unit stride distribution of data within each data set
- User-specified scaling, transform sign
- Multiple one-dimensional transforms on single call
- Supports FFTW interface through wrappers

# Introduction, Cluster FFT

- These functions are available only for Intel® 64
- Works with MPI using BLACS
- 1, 2, 3 and multidimensional (up to the order of 7)
- Require basic MPI programming skills
- Supported Intel® MPI, Open MPI, MPICH and SGI MPT
- Same interface as the DFT from standard MKL

# MKL DFTI API

## Overview

- DFTI_DESCRIPTOR_HANDLE
- 5 base functions: Create, Adjust(optional), Commit, Compute, Free
- numerous configuration parameters

## See also :

http://portal.acm.org/citation.cfm?id=1114271)

DFTI_PRECISION

DFTI_DIMENSION, DFTI_LENGTHS

DFTI_PLACEMENT

DFTI_THREAD_LIMIT

DFTI_INPUT_STRIDES, FTI_OUTPUT_STRIDES

DFTI_NUMBER_OF_TRANSFORMS

DFTI_COMPLEX_STORAGE

DFTI_REAL_STORAGE

DFTI_CONJUGATE_EVEN_STORAGE

……..

# MKL DFTI interface routines

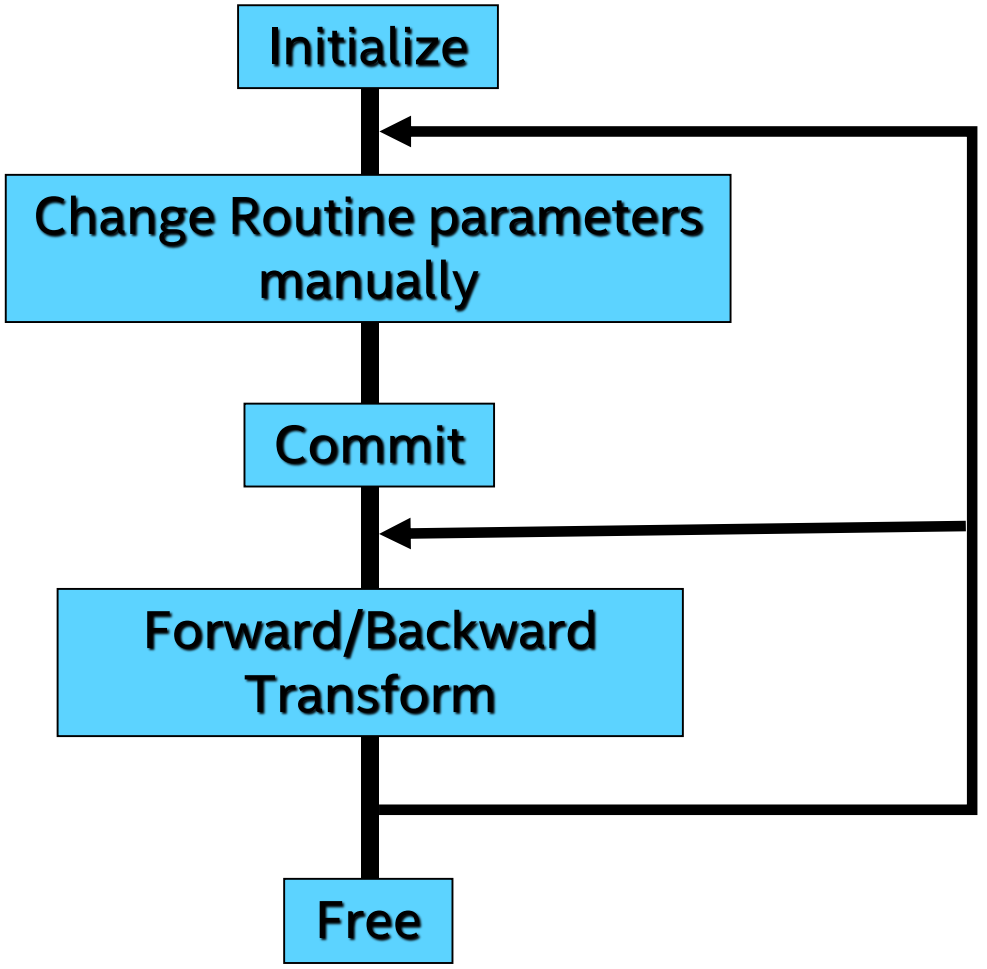
```
DftiCreateDescriptor

DftiSetValue

DftiCommitDescriptor

DftiComputeForward
DftiComputeBackward

DftiFreeDescriptor
```



# MKL DFTI API, example

Complex-to-complex 1D transform for double precision data not inplace.

```
/* Create Dfti descriptor for 1D double precision  transform */
Status = DftiCreateDescriptor( &Desc_Handle, DFTI_DOUBLE, DFTI_COMPLEX, 1, n );

/* Set placement of result DFTI_NOT_INPLACE */
Status = DftiSetValue(Desc_Handle, DFTI_PLACEMENT, DFTI_NOT_INPLACE);

/* Commit Dfti descriptor */
Status = DftiCommitDescriptor( Desc_Handle );

/* Compute Forward transform */
Status = DftiComputeForward(Desc_Handle, x_in, x_out);

/*  Free DFTI descriptor */
Status = DftiFreeDescriptor(&Desc_Handle);
```

# Requirements

- Intel® Parallel Studio XE 2020 Composer Edition with Intel® C++ Compiler
- Linux* OS supported by Intel® C++ Compiler
- Recommended to have at least 3nd **generation Intel® Core™ processor** (with Intel® AVX2)
- Setting the PATH, LIB, and INCLUDE environment variables

## Compiler:

source /opt/intel/compilers_and_libraries_2020.1.127/linux/bin/compilervars.sh intel64

## MKL:

or source <mklroot>/bin/mklvars.sh intel64

check the version: **echo $MKLROOT** → /opt/intel/compilers_and_libraries_2020.1.217/linux/mkl/

# Demo – General Case, 1D FFT, in-place

**Directory**: ~/workshop/mkl/**FFT**

- Review test: **test_dft_1d.c**
- Compiling: **icc –mkl test_dft_1D.c**
- **export MKL_NUM_THREADS=1**
- **./a.out 10**
- Outputs**:**

```
[gfedorov@skx2 4FFT]$ ./a.out 10
DFTI_LENGTHS       = {10000000}
ExecTime        == 2.862838,sec
Performance   ==  4.47 GFlops...
```

* -- Intel(R) Xeon(R) Gold 6148 CPU @ 2.40GHz ,192 GB RAM

# Demo – General Case, 1D FFT, Usage Modes

## Verbose Mode

- export MKL_VERBOSE=1
- $ ./a.out 10
- **Output**:

MKL_VERBOSE Intel(R) MKL 2020.0 Update 1 Product build 20200208 for Intel(R) 64 architecture Intel(R) Advanced Vector Extensions 512 (Intel(R) AVX-512) enabled processors, Lnx 2.40GHz intel_thread

MKL_VERBOSE FFT(**dcfi**10000000,tLim:1,desc:0x1fd3e40) 259.66ms CNR:OFF Dyn:1 FastMM:1 TID:0 NThr:1
ExecTime == 2.847701,sec
Performance == 4.49 GFlops...

# Demo – General Case, 1D FFT, Threading, OMP

OpenMP: mkl_intel_thread.[lib,dll], libmkl_intel_thread.[a,so]

TBB : mkl_tbb_thread.lib[lib,dll], libmkl_tbb_thread.[a,so]

Sequential: mkl_sequential.[lib,dll], libmkl_sequential.[a.so]

Sequential mode: ./a.out {1, 10, 100} ( export MKL_NUM_THREADS=1)

./a.out 1 …Performance = 6.2 GFlops…
./a.out 10 …Performance = 2.9 GFlops…
./a.out 100 …Performance = 4.8 GFlops…

Scaling: Review and **./run_ompthr_scaling.sh** ( icc –mkl=parallel test.c or unset MKL_NUM_THREADS )

Intel(R) Xeon(R) Gold 6148 CPU @ 2.40GHz ,192 GB RAM results:

| size*10^6/threads | 1 | 2 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|---|
| 100 | 4.8 | 5.8 | 11.4 | 20.7 | 35.1 | 43.6 |
| 10 | 4.5 | 6.0 | 11.6 | 21.1 | 31.4 | 40.0 |
| 1 | 6.4 | 7.8 | 14.6 | 22.5 | 40.9 | 58.3 |

# Demo – General Case, 1D FFT, Threading, TBB

cd ../tbb (Directory: ~workshop/mkl/FFT/tbb)

- review makefile:

```
-Wl,--start-group \
${MKLROOT}/lib/intel64/libmkl_intel_lp64.a \
${MKLROOT}/lib/intel64/libmkl_tbb_thread.a \
${MKLROOT}/lib/intel64/libmkl_core.a \
-Wl,--end-group -ltbb -lstdc++ -lpthread -lm -ldl
```

- make

- ./run.sh

- Observation ☺?

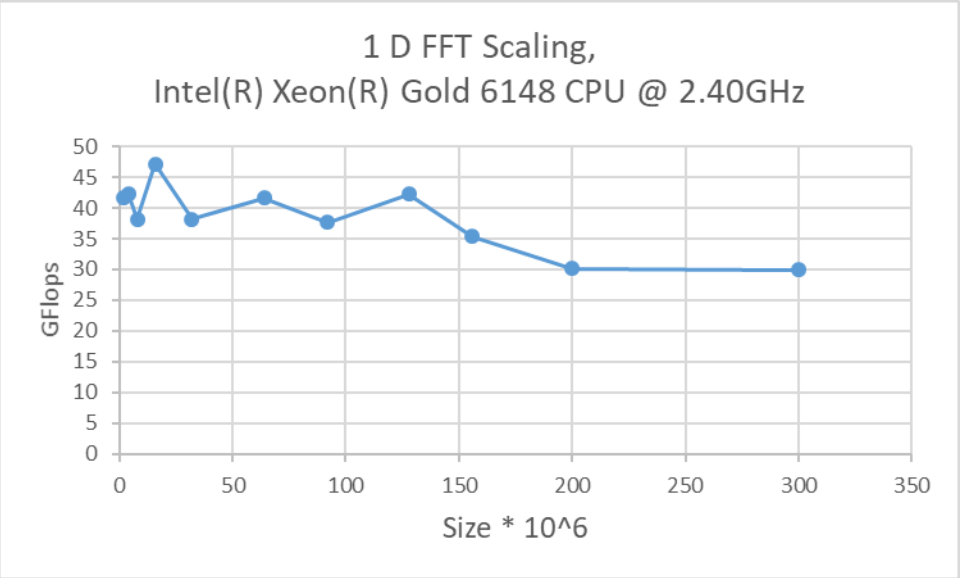
# Demo – General Case, 1D FFT, Size Scaling

## Problem Size Scaling

cd .. (Directory: <mkl_workshop>/FFT )

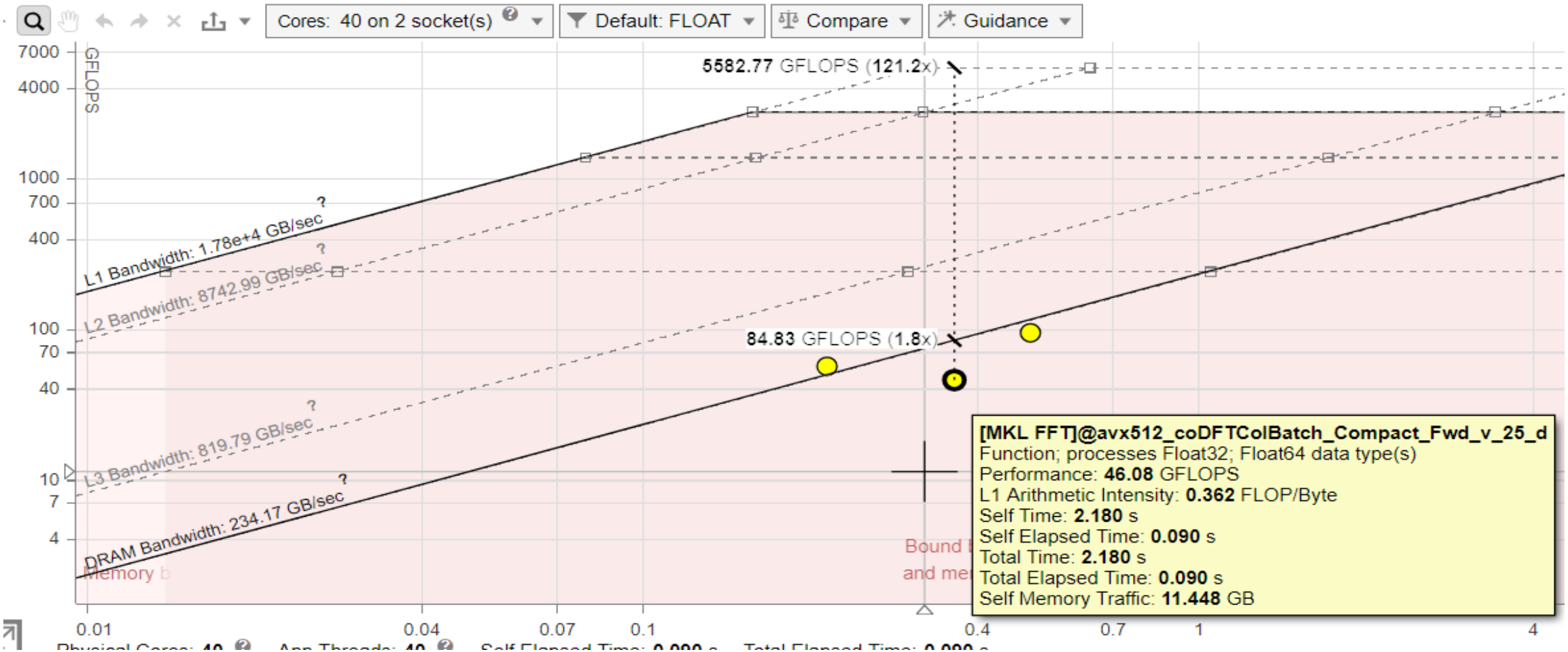
- Review run_problem_size_scaling.sh
- icc –mkl test_dft_1d.c
- ./run_problem_size_scaling.sh

Do you see smth like as follows:




**Solution - Cluster FFT!**

# Intel® Adviser, Roofline Analysis. Memory bound



# Demo – 2DFFT

## 2D FFT using batch of 1D FFT or single 2DFFT calls

➢ **Review test_fft_2d_by_1d.c**

```
DftiCreateDescriptor(&hand_x, DFTI_DOUBLE, DFTI_COMPLEX, 1, M);
DftiSetValue(hand_x, DFTI_NUMBER_OF_TRANSFORMS, N )
DftiSetValue(hand_x, DFTI_INPUT_DISTANCE, M);

DftiCreateDescriptor(&hand_y, DFTI_DOUBLE, DFTI_COMPLEX, 1, M);
DftiSetValue(hand_y, DFTI_NUMBER_OF_TRANSFORMS, N )
DftiSetValue(&hand_y, DFTI_INPUT_DISTANCE, M);

DftiComputeForward(hand_x, data);
DftiComputeForward(hand_y, data);

DftiFreeDescriptor(&hand_x);
DftiFreeDescriptor(&hand_y);
```

```
Int clengths[2] = {M, N};
DftiCreateDescriptor
(&hand_xy, DFTI_DOUBLE, DFTI_COMPLEX, 2, clengths);

DftiSetValue
(hand_xy, DFTI_NUMBER_OF_TRANSFORMS, 1);

DftiComputeForward (hand_xy, data);

DftiFreeDescriptor(&hand_xy);
```

# Demo – 2DFFT, cont.

- **icc -mkl test_fft_2d_by_1d.c**
- **./a.out**

MKL_VERBOSE Intel(R) **MKL 2020.0** Update 1 Product build 20200208 for Intel(R) 64 architecture Intel(R) Advanced Vector Extensions 512 (Intel(R) **AVX-512**) enabled processors, Lnx 2.40GHz intel_thread
MKL_VERBOSE FFT(dcfi1920x1200,tLim:40,desc:0x101fe40) 39.31ms CNR:OFF Dyn:1 FastMM:1 TID:0 NThr:40
MKL_VERBOSE FFT(dcfi1200x1920,tLim:40,desc:0x103c180) 2.96ms CNR:OFF Dyn:1 FastMM:1 TID:0 NThr:40
Verify the result, errthr = 2.35e-14
Verified, maximum error was 3.29e-16
MKL_VERBOSE FFT(dcfi1200x1920,tLim:40,desc:0x1043400) 2.34ms CNR:OFF Dyn:1 FastMM:1 TID:0 NThr:40
Verify the result, errthr = 2.35e-14
Verified, maximum error was 3.29e-16
Execution time of **1D calls** == **4.243274e-02**
Execution time of **2D call** == **2.373712e-03**

# FFTW API Support

## Intel MKL supports FFTW2 and FFTW3 APIs

**FFTW3** API:

- interfaces are integrated in Intel MKL by default

- Option to build – see interfaces/fftw*/makefiles

**FFTW2 –** are not integrated: Build standalone library of FFTW2 C/F wrappers to Intel(R) MKL.

**MKLROOT/interfaces:** fftw2xc, fftw2xf, fftw2x_cdft, fftw3xc, fftw3xf, fftw3x_cdft

**Examples:** MKLROOT\examples:

fftw2xc, fftw2xf, fftw2x_cdft, fftw3xc, fftw3xf, fftw3xf_cdft and fftw3x_cdft

**Note:** The FFTW2 and FFTW3 interfaces are not compatible with each other. Avoid linking to both of them.

# DEMO – FFTW, FFT

Directory: ~/workshop/mkl/FFT/**fftw**

- prebuilt - fftw-3.3.7

➢ Review **fftw.c**, **mkl_fftw.c** and **makefile**

  ➢ make

  ➢ export LD_LIBRARY_PATH=.:$LD_LIBRARY_PATH;

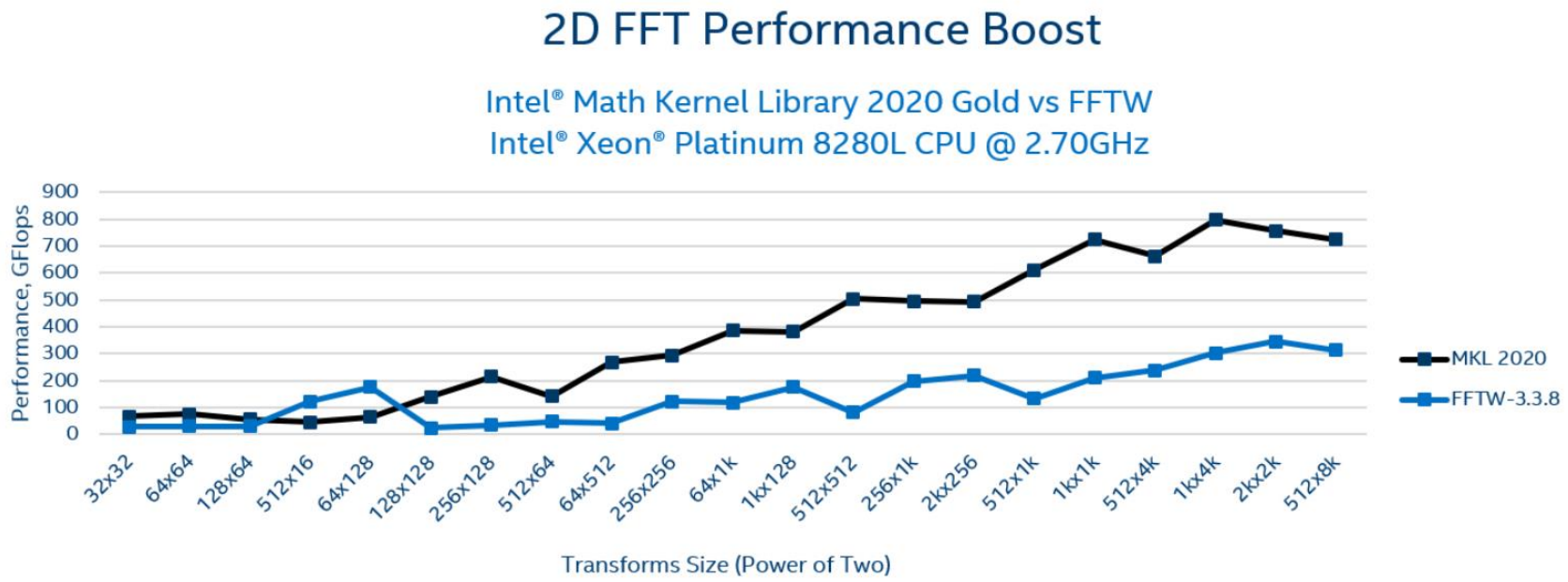
  ➢ ./run.sh

➢ **Observation ?**

➢ export MKL_VERBOSE and ./run.sh

# MKL 2020 – FFTW, FFT, benchmarking

https://software.intel.com/en-us/mkl/features/benchmarks

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Performance results are based on testing as of **November 5, 2019** and may not reflect all publicly available security updates. See configuration disclosure for details. No product can be absolutely secure.

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**Configuration:** Testing by Intel as of **November 5, 2019**. Intel® Xeon® Platinum 8280L 2x28@2.7GHz 192GB DDR4-2666 using Intel® Math Kernel Library 2020.

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# Performance Tips

- KMP_AFFINITY=compact, granularity=fine
- MKL_DYNAMIC=false
- MKL_NUM_THREADS *varies*
- Align data
  - help vector load/store
  - Avoid cache-thrashing alignments (e.g. 2Kx2K)
- Use batched transformation where possible
- Know optimize radices: 2, 3, 5, 7, 11, 13

# Intel MKL Resources

Intel® MKL website:

– https://software.intel.com/en-us/intel-mkl

Intel MKL forum:

– https://software.intel.com/en-us/forums/intel-math-kernel-library

Intel® MKL benchmarks:

– https://software.intel.com/en-us/intel-mkl/benchmarks#

Intel® MKL link line advisor:

– http://software.intel.com/en-us/articles/intel-mkl-link-line-advisor/

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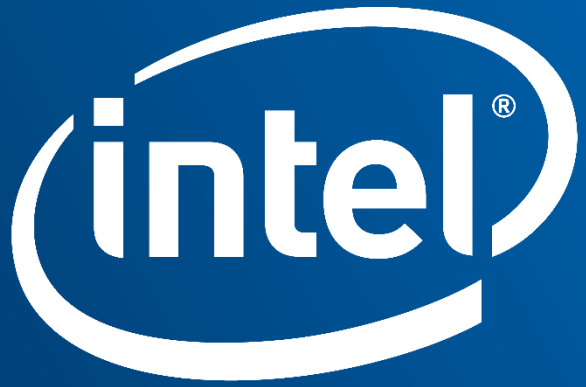


Software

# Performance Tips, Alignment

- Review: test_dft_1d_alignments.c ( mkl_malloc/mkl_free vs malloc/free )
- icc –mkl test_dft_1d_alignments.c
- ./a.out