ADVENTURES IN BATCHED LINEAR ALGEBRA IN INTEL® MATH KERNEL LIBRARY

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Agenda

• Performance challenges and solutions
• Batched linear algebra
• Alternative data layout: compact APIs
• Just-in-time (JIT) generation
• Summary and Intel MKL resources
## How Intel MKL gets performance

**More Cores → More Threads → Wider Vectors**

<table>
<thead>
<tr>
<th>Processor Series</th>
<th>Up to Core(s)</th>
<th>Up to Threads</th>
<th>SIMD Width</th>
<th>Vector ISA</th>
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<td>Intel® SSE3</td>
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<td>Intel® AVX-512</td>
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1. Product specification for launched and shipped products available on ark.intel.com.
Classification of sizes and performance challenges

Small Sizes
• M, N, K < 20
• Challenges: High function call overheads, low vectorization, low parallelization
• Solutions: Batch API, Compact API, MKL_DIRECT_CALL, and JIT GEMM

Medium Sizes
• 20 < M, N, K < 500
• Challenges: Low parallelization, high copy overheads
• Solutions: Batch API and Pack API

Large Sizes
• M, N, K > 5000
• Performance close to machine's theoretical peak
Introduction to batched linear algebra

- Execute independent general matrix multiplication (GEMM) operations simultaneously with one function call
- Ensure no data dependency between the operations
- Take advantage of all cores even for small-medium sizes (M, N, K < 500)
- Minimize library overheads
- Some code modification is required to group same size matrices together

\[
\begin{align*}
C_1 &= \alpha \cdot \text{op}(A^1) \cdot \text{op}(B^1) + \beta \cdot C_1 \\
C_2 &= \alpha \cdot \text{op}(A^2) \cdot \text{op}(B^2) + \beta \cdot C_2 \\
C_3 &= \alpha \cdot \text{op}(A^3) \cdot \text{op}(B^3) + \beta \cdot C_3
\end{align*}
\]

Execute in parallel assuming no pointer aliasing

\[
\begin{align*}
C_2 &= \alpha \cdot \text{op}(A^4) \cdot \text{op}(B^4) + \beta \cdot C_2
\end{align*}
\]

Wait for a previous write to \(C_2\)
Group concept in batch API

- Group: set of GEMM operations with same input parameters (matrix pointers can be different)

- Transpose, size, leading dimensions, alpha, beta

- One GEMM_BATCH call can handle one or more groups
API advantages of groups

- Same function can handle 1 or more groups
- Consistent level of redirection for function parameters
  - Integer → array of integers
  - Pointer → array of pointers
- Smaller parameter arrays
- Minimal error checking needed
Performance opportunities for batching with groups

• Minimize library overheads for small sizes
  • Reduce function call overheads
  • Do error checking once for each GEMM group
• Better exploit parallelism available in many-/multi-core processors
• Potential performance techniques
  • Prefetch the matrix blocks across GEMM calls
  • Pack matrix once if used throughout group
  • Just-in-time (JIT) generation to create GEMM kernel for group
Compact API

- A new data layout to better utilize vectorization on large numbers of same size matrices
- Matrix elements with same index are interleaved in memory
- Size of the subgroup is SIMD length to fully utilize SIMD instructions
- Example reformatting of 3x2 matrices with subgroup size = 4:
Compact APIs Workflow

Transform the data from standard format into compact format:

```c
MKL_COMPACT_PACK compact_format = mkl_get_format_compact();
```

```c
a_size = mkl_dget_size_compact(lda, k, compact_format, num_matrix);
```

```c
mkl_dgepack_compact(layout, m, k, a_array, lda, a_c, lda, compact_format, num_matrix);
```

Perform multiple operations on the compact data:

```c
mkl_dgemm_compact(layout, transa, transb, m, n, k, alpha, a_c, lda, b_c, ldb, beta, c_c, ldc, compact_format, num_matrix);
```

Transform the data from compact format into standard format:

```c
mkl_dgeunpack_compact(layout, m, n, c_array, ldc, c_c, ldc, compact_format, num_matrix);
```
JIT (Just-In-Time) GEMM Overview

• Generate (JIT) a customized kernel at run time to decrease overheads

• Use preprocessor macro MKL_DIRECT_CALL_JIT or MKL_DIRECT_CALL_SEQ_JIT
  • No changes to user code
  • Intel MKL may JIT a specific kernel
  • Kernels are stored in an internal hash table to amortize cost of generation

• Use new JIT APIs
  • User responsible for managing kernels
  • Eliminates more overheads for even better performance
JIT APIs Workflow

Create a handle and generate GEMM kernel:

```c
mkl_jit_status_t status = mkl_jit_create_sgemm(&jit_handle,
    layout, transa, transb, m, n, k, alpha, lda, ldb, beta, ldc);
```

Get kernel associated with handle:

```c
sgemm_jit_kernel_t kernel = mkl_jit_get_sgemm_ptr(jit_handle);
```

Repeatedly execute the GEMM kernel:

```c
kernel(jit_handle, a, b, c);
```

Destroy the created handle/GEMM kernel:

```c
mkl_jit_destroy(jit_handle);
```
JIT DGEMM, SGEMM on Intel® Xeon® Platinum Processor

Optimized by Intel® Math Kernel Library 2019 Update 2 for Intel® Xeon® Platinum Processor

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Configuration:
Testing by Intel as of February 2019: Intel® Xeon® Platinum 8180 H0 205W 2x28@2.5GHz 192GB DDR4-2666
Benchmark Source: Intel® Corporation.

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Final Remarks

• Small/medium matrices have various performance challenges
• Batching better utilizes multi- and many-cores for small/medium matrices
• Groups contain matrices with same parameters (size, leading dimension, etc.)
• Intel MKL batch API combines ease-of-use with performance opportunities
• Can interleave data to increase vectorization across matrices
• Intel MKL compact API can significantly improve performance for small sizes
• Just-in-time (JIT) generation can reduce overheads for small sizes, by creating custom kernel at run-time and re-using it many times
Intel MKL resources

- No cost option for Intel MKL: https://software.intel.com/en-us/articles/free-mkl
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