Towards Variable Size Batch BLAS (and LAPACK)
A sneak peek into MAGMA’s \textit{vbatched} routines

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Workshop on Batched, Reproducible, and Reduced Precision BLAS

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Outline

1 Introduction

2 Status of MAGMA vbatched routines

3 Design Techniques

4 Performance Results

5 Summary
## Outline

1. **Introduction**
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Motivation

Why do we need \textit{vbatched} computation?

- In general, applications may require solving many independent problems that are different in size
  - Using fixed size approach with padding is not a good idea
- A typical example is \textit{sparse direct solvers}
  - Ongoing work with Tim Davis (TAMU)
  - QR, LU, and Cholesky on many relatively small matrices of different sizes
Do we have good starting points?

CPUs: **YES**

- Problems fits in the CPU relatively large caches
- Optimized routines (e.g. from MKL) can be used
- Use one core per matrix at a time

```c
// set BLAS #threads = 1
// set OpenMP #threads = 8, 16, 32, ... etc

#pragma omp parallel for schedule(dynamic)
for (int i=0; i < batchCount; i++){
  cpu_dgemm( TRANSA[i], TRANSB[i],
             &M[i], &N[i], &K[i],
             &alpha[i], Aarray[i], &lda[i],
             Barray[i], &ldb[i],
             &beta[i] , Carray[i], &ldc[i] );
}
Do we have good starting points? “cont.”

CPUs: YES

Example: **DGEMM** using MKL + OpenMP (16-core Intel Xeon E5-2690 @ 2.9 GHz)

Batches of square matrices with random sizes
Do we have good starting points? “cont.”

GPUs: NO

- No large caches
- Most existing BLAS kernels are designed/tuned for large matrices
  - Use **heavyweight thread blocks (TBs)**
  - In batched workloads, **throughput of TB execution** is crucial to performance
- MAGMA uses hybrid (CPU + GPU) approach for most factorization and solve routines
  - Communication kills the performance for small matrices
- A **full GPU solution** is required
  - We always start by developing the fixed size variant of the routine
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Status of the MAGMA \textit{vbatched} routines

\textbf{BLAS}

- Level-3
  - Ready: GEMM, TRSM, SYRK, HERK, SYR2K, and HER2K
  - Dev.: TRMM, SYMM, and HEMM
- Level-2
  - Ready: GEMV
  - Dev.: SYMV
- Level-1
  - Ready: AXPY

\textbf{LAPACK}

- One-sided Factorization
  - Ready: Cholesky (POTRF)
  - Dev.: LU (GETRF) and QR (GEQRF)
Interface of MAGMA’s vhbatched routines

- Variable size **BUT** the same problem settings *(for now)*
  - e.g., `TRANSX`, `UPLO`, and `SIDE` are all the same
  - Different settings are doable, but might impact performance.

```c
void magmablas_dgemm_vbatched(
    enum transA, enum transB,
    int* m, int* n, int* k,
    double alpha, double ** Aarray, int* lda,
    double ** Barray, int* ldb,
    double beta, double ** Carray, int* ldc,
    int batchCount, magma_queue_t queue );
```
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Two Design Approaches

1 Early Termination Mechanisms (ETMs)

- Computational kernel is launched by the CPU
- The kernel must accommodate the biggest matrix
  - e.g., we need $\text{max}_M$, $\text{max}_N$, and $\text{max}_K$ in GEMM
- ETMs identifies threads with no work to do for smaller matrices

Pros
- Minor overhead (only one kernel launch)
- The CPU decides the tuning parameters

Cons
- Needs the maximum dimensions
  (exposed to user vs. computed internally)
- The selection criteria for tuning parameters is tricky
  (right now, based on the maximum dimensions)
Two Design Approaches “cont.”

2 Dynamic Parallelism

- Computational kernels are launched on the GPU
- The CPU launches one master kernel with as many threads \( \text{batchCount} \)
- Each master thread launches a kernel for one matrix

Pros
- No need to know the maximum dimensions
- Choose the best tuning parameters for each matrix

Cons
- Large overhead (launches \( \text{batchCount}+1 \) kernels)
- At least compute capability 3.5
ETM vs. Dynamic Parallelism

Consider a GEMM kernel for with $\text{batchCount} = 3$

**ETM**
- vbatched kernel (CPU)
- (3, 3, 3) grid configuration

**Dynamic Parallelism**
- parent kernel (CPU)
- (1, 1, 3) grid configuration

### ETM

- $3 \times 3$ subgrid ($:, :, 0$)
- $3 \times 3$ subgrid ($:, :, 1$)
- $3 \times 3$ subgrid ($:, :, 2$)

### Dynamic Parallelism

- th.$(0, 0, 0)$
- GEMM (GPU)
- (2, 3, 1) grid

- th.$(0, 0, 1)$
- GEMM (GPU)
- (3, 3, 1) grid

- th.$(0, 0, 2)$
- GEMM (GPU)
- (2, 1, 1) grid
Optimization Techniques

1. Conventional techniques
   - Register blocking, prefetching, loop unrolling, ... etc
   - **BUT** not necessarily maximizing resources per TB

2. Kernel Fusion
   - Fused batched BLAS kernels for very small matrices
   - Saves global memory traffic

3. Implicit Sorting
   - Similar computational steps called several times
     (e.g. panel/update)
   - At each step, consider sizes within a relatively small window
   - Delay processing of smaller matrices
     (load balancing)
GEMM Tuning: Aiming for The Best Performance

- Two phases of tuning
  1. Tuning the MAGMA-BLAS kernel
     - Selection of the best tuning parameters according to problem setting/precision/sizes
     - Consider typical test cases found in LAPACK
     - Further details: Abdelfattah et al., ISC’16
  2. Selecting the best kernel out there
     - Two MAGMA-BLAS kernels (ETM vs dynamic parallelism)
     - Streamed cuBLAS GEMM

Eventually, we want the best performance when we call magma_Xgemm_vbatched
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Experimental Setup

- 1 × Kepler generation GPU (Tesla K40c @ 745 MHz, ECC on)
- CUDA Toolkit 7.0
- Randomly generated sizes with a uniform distribution

Performance Comparisons
- MAGMA-vbatched vs. non-batch reference implementations (using cuBLAS)
Matrix-matrix Multiplication (DGEMM)

- Speedups from $2.5 \times$ up to $50+ \times$
Triangular Solve (DTRSM)

- Speedups from $7.9 \times$ up to $18.4 \times$
Matrix-vector (DGEMV)

![Graph showing speedups from 4.4× up to 50+×](image)

- Speedups from $4.4 \times$ up to $50+ \times$
Cholesky Factorization (DPOTRF)

- **Against padding**: speedups from $1.24 \times$ up to $3.8 \times$
- **Against hybrid**: speedups from $28 \times$ up to $200+ \times$
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Conclusion and Future Work

- **Conclusion**
  - Variable size batched computations can run efficiently on the GPU
  - New techniques are required
  - Autotuning is challenging (sizes, precision, batch count, distribution)

- **What’s Next?**
  - Complete the set of BLAS routines
  - More LAPACK algorithms (LU and QR)
  - Test against different size distributions
  - Error reporting
Thank You!