BLAS to CUBLAS Transformation: Report for COMPOSE-HPC Project.

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1 Introduction

Many compute intensive scientific applications make heavy use of tuned numerical libraries such as BLAS [1]. Equivalent libraries such as CUBLAS [2] provide means to harness the computational resources of GPUs thereby achieving significant performance improvements. Replacing the original library calls in existing applications with the GPU version is tedious and needs more thought due to the additional complication of adding memory management and other supporting code to make the GPU library calls work as expected and thereby reap the performance benefits.

This document describes an annotation guided transformation that transforms C/C++ source code that use BLAS calls into CUDA code containing CUBLAS calls along with the appropriate memory management and support code. The transformation is built using the ROSE compiler framework [3] and Coccinelle [4], a term rewriting system.

2 Overview

An overview of the steps involved in the transformation is shown in Figure 1. A simple translator built using the ROSE compiler is run on the input source code provided and produces a new source code wherein some terms are rewritten such that the overall behaviour of the original input source does not change. The new source code is then passed to the automated annotation stage where all the BLAS calls in the code are annotated if the user desires to transform all the BLAS calls in his code to CUBLAS calls. If the user desires to transform only a few BLAS calls, the automated annotation stage is skipped and the user is expected to manually annotate the BLAS calls he desires to transform. The annotated input source is then passed to the transformation stage where the actual transformation takes place and the appropriate CUDA code is generated.

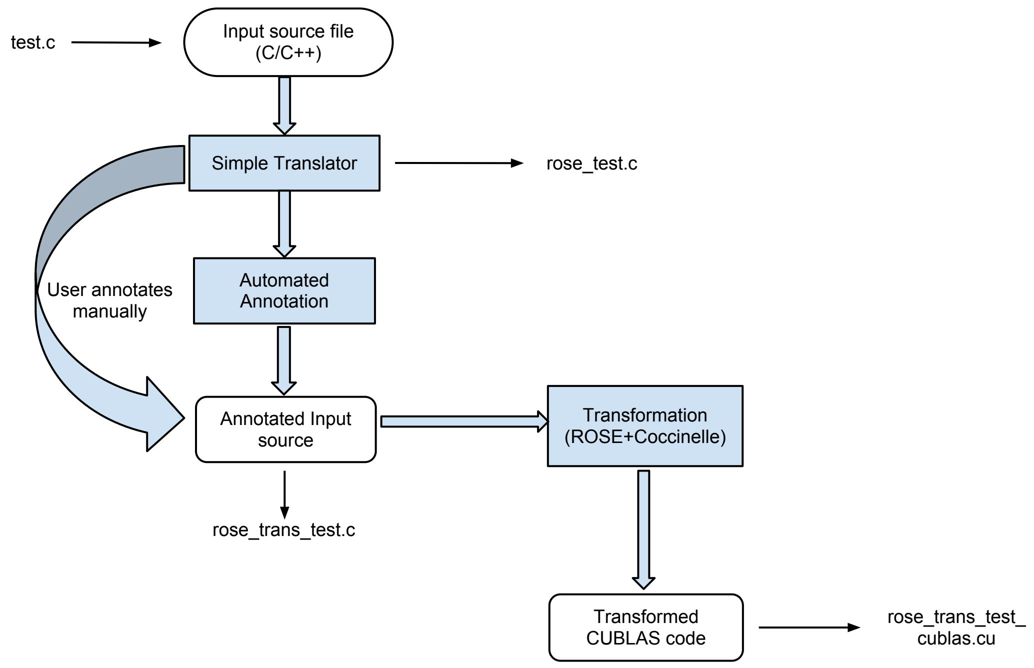

Figure 1: Overview of the Transformation.

3 Transformation Details

This section explains each stage of the transformation in more detail.

3.1 Input source code

The annotation associated with a BLAS call must be placed in juxtaposition with the BLAS calls to which they are intended to apply. An example follows (annotation shown within comments):

/*% BLAS_TO_CUBLAS prefix = device1 */
$cblas\_sgemm(CblasRowMajor, CblasNoTrans, CblasNoTrans,$
$n, n, n, 1.0, \&a[0], n, \&b[bi + ci], n, 1.0, c, n);$

The value of *prefix* could be any valid identifier names. New variables are introduced into the transformed code and the names of these variables are prefixed by this user provided identifier names to avoid name clashes with existing variables in the original code.

3.2 Simple Translator

The simple translator is built using ROSE. It contains a call to the ROSE frontend which generates the abstract syntax tree (AST) ROSE uses for the input source provided, and a call to backend unparses the AST to generate the same source code with some terms rewritten in such a way that the overall behaviour of the input source code provided does not change.

The need for the Simple Translator arises because the transformation tries to extract information (such as array references) from the annotated BLAS call for the sake of generating a Coccinelle patch later to transform the given input source. The patch contains the rewritten terms, which would not match with the terms in the original input source and the transformation would not be applied because Coccinelle would not find the BLAS call to be matched (since it is looking for the rewritten BLAS call). For example consider the BLAS call in 3.1. When ROSE parses this code and builds the AST and we try to extract the array names so that we can write a patch using Coccinelle to match the BLAS call and replace it with the appropriate CUDA code. The rewritten BLAS call looks like

$$cblas\_sgemm(CblasRowMajor, CblasNoTrans, CblasNoTrans,\\ n, n, n, 1.0, (a + 0), n, (b + (bi + ci)), n, 1.0, c, n);$$

The array reference &a[0] in the BLAS call in 3.1 and (a + 0) here mean the same thing. When ROSE builds the AST and the transformation tries to unparse it in order to determine the array references, the array references are rewritten without affecting the behaviour of the input source code provided. If the Simple Translator is not used to generate this code first, the Coccinelle patch generated would try to match the rewritten BLAS call (for replacing it with CUDA code) with the one in 3.1 and would fail in doing so because the code pattern is different.

3.3 Automated Annotation

The source code from simple translator is fed to the automate annotation stage. If the user desires to annotate all the BLAS calls he can leave it upto the transformation to do this. A Coccinelle patch takes care of this. It annotates all BLAS calls present in the input source and with each annotation a unique prefix is generated. This prefix cannot be specified by user as of now, but support for specifying the prefix will be added soon. Annotations can be added manually by the user only to those BLAS calls that the user desires to transform. In this case the automated annotation stage is skipped.

3.4 Transformation

The annotated source is passed on to the actual transformation phase. A new header (*cublas.h*) needs to be inserted into the transformed code because the transformed code would be using the CUBLAS API. It is inserted before the first header include found in the input source provided.

To understand the details of the actual transformation consider again the *sgemm* BLAS call:

$$cblas\_sgemm(CblasRowMajor, CblasNoTrans, CblasNoTrans,\\ n, n, n, 1.0, (a + 0), n, (b + (bi + ci)), n, 1.0, c, n);$$

The array references are matched explicitly to avoid ambiguity among the different *sgemm* calls in the input source. If we do not explicitly match the array references and rather match whatever is there, all the *sgemm* calls in the input source get transformed even if they are not annotated. As for the rest of the arguments they are matched with whatever is there, except that for those cases where calls use the CBLAS API, there is some more work involved which is explained in the following text. If we have two *sgemm* calls that are exactly the same (have the exact same arguments) both are transformed even if only one of them is annotated.

The steps in the transformation stage could be summarized as follows. The array references are extracted from the above sgemm call using ROSE API. The storage order and transpose options are also determined because this call uses the CBLAS API which allows specifying row-major storage for arrays and CUBLAS assumes only column-major storage for arrays. These options are defined as enumerated types in the CBLAS API. CUBLAS routines accept character constants for transpose options. Hence the transformation cannot simply use the transpose options that are present in the regular BLAS calls using the CBLAS API with CUBLAS calls. The transformation would need to determine what the transpose options are so that it could pass the equivalent options that conform with the CUBLAS API. It may not be possible to determine them always since variables containing the transpose and storage-order options might be passed as arguments. In such cases the logic for determining and passing the equivalent options to the CUBLAS call is generated as part of transformed code. If the input source uses FORTRAN BLAS API (which assumes column-major storage for arrays), then the options from the BLAS call could be passed as is to the CUBLAS call that is going to be generated. A Coccinelle patch is generated for each annotated BLAS call. A single patch file per input source file containing patches for all the annotated BLAS calls is generated. These patches specify a code pattern to be matched and a replacement pattern to be substituted which are processed by Coccinelle. The Cocinelle patch (complete patch not shown) for the BLAS call being discussed is as follows:

```
@disable paren@
expression order,transA,transB;
expression m,n,k,alpha,lda,ldb,beta,ldc;
@@
- cblas_sgemm(order,transA,transB,m,n,k,alpha,
(a + 0), lda, (b + (bi + ci)),ldb,beta,c,ldc);

+ /* Allocate device memory */
+ /* Copy matrices to device */
+ /* Storage Order Warning */

+ /* CUBLAS call */
+ cublasSgemm('N','N',m,n,k,alpha,device1_A,lda,
              device1_B,ldb,beta,device1_C,ldc);

+ /* Copy result array back to host */
+ /* Free device memory */
```

4 Transformed Code

- Depending on the type of BLAS library being used, the non-standard headers and external function calls in the input source (C sources only) need to be enclosed within *extern* "*C* " and this needs to be done by the user. The reason is the transformed cuda code when compiled with the nVidia C compiler (nvcc), the external libraries are linked using g++.
- If the original input source uses the CBLAS API and row-major storage for arrays is specified the transformed code would have a warning nested in a comment above the CUBLAS call saying the original BLAS call assumed row-major storage for the arrays.
- Certain BLAS routines listed below are not handled by the transformation since CUBLAS does not provide them. They are listed as follows:
  - BLAS 3 -> {c,z}gemm3m, {sc,dz}gemm, {sc,dz}gemv (Intel MKL only)
  - BLAS 2 -> {s,d}gem2vu, {c,z}gem2vc (Intel MKL only)
  - BLAS 1 -> {ds,sds}dot, {d,s}cabs1
  - CUDA BLAS library provides routines for rotg, rotmg for completeness sake and are run on the CPU.

5 Future Work

- The transformation currently works under an unrealistic assumption that the memory available on the GPU is atleast equal that of the CPU memory, which is not always true in practice. Another way to look at this is the transformation assumes that the computation fits within GPU memory. This assumption would be removed in later iterations of the transformation by generating code for moving data between CPU and GPU memory if the entire computation would not fit in GPU memory.
- The transformation also does not take advantage of multiple GPUs (when available) in a system since the CUBLAS library does not auto-parallelize across multiple GPUs.
- Currently the transformation does not provide support for task parallelism. Task parallelism involves performing two or more completely different tasks in parallel. This approach is especially useful when the computation performed by a single task is relatively small and is not enough to fill the GPU with work. Such tasks could be identified by the user and could be made explicit through an annotation so that the transformation knows which tasks could be executed in parallel to efficiently utilize the GPU resources.
- Use name mangling provided by ROSE to avoid name clashes instead of the user having to specify a prefix for new variables in transformed code.

- The transformation currently follows the CUBLAS library version 3.2 and hence lacks the new features provided by version 4.0. Later iterations of the transformation would include those new features for generating more efficient CUDA code.

6 Code Availability

The sources for the transformation are available at `http://sourceforge.net/projects/compose-hpc`. The sub-direcotry paul/demo/blas2cublas contains the source code and testcases along with a README file with instructions for getting the transformation working on your machine.

References

[1] J. J. Dongarra, Jeremy Du Croz, Sven Hammarling, and I. S. Duff, "A set of level 3 basic linear algebra subprograms," *ACM Trans. Math. Softw.*, vol. 16, pp. 1–17, March 1990.

[2] nVidia Corporation, *CUDA CUBLAS Library 3.2*, Aug. 2010.

[3] "ROSE Compiler Framework," http://rosecompiler.org/.

[4] Yoann Padioleau, Julia L. Lawall, René Rydhof Hansen, and Gilles Muller, "Documenting and automating collateral evolutions in linux device drivers," in *EuroSys 2008*, Glasgow, Scotland, Mar. 2008, pp. 247–260.