Spla: Generalized Sparse Linear Algebra Library with Vendor-Agnostic GPUs Acceleration

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***Abstract*—Scalable high-performance graph analysis is a nontrivial challenge. Usage of sparse linear algebra operations as building blocks for graph analysis algorithms, which is a core idea of GraphBLAS standard, is a promising way to attack it. While it is known that sparse linear algebra operations can be efficiently implemented on GPU, full GraphBLAS implementation on GPU is a nontrivial task that is almost solved by GraphBLAST project. It is shown that utilization of GPUs for GraphBLAS implementation significantly improves performance. But GraphBLAST is not portable because it is based on Nvidia Cuda. In this work we propose Spla library which aims to solve this problem using OpenCL API for vendor-agnostic GPUs accelerated computations. Evaluation shows that the proposed solution demonstrates performance comparable with GraphBLAST, outperforming it up to 36 times in some cases, and remains portable across different GPUs vendors.**

***Index Terms*—graphs, algorithms, graph analysis, sparse linear algebra, GraphBLAS, GPGPU, OpenCL**

I. Introduction

Scalable high-performance graph analysis is a challenge. CuSha [1] and Gunrock [2] show that the utilization of GPUs can improve the performance of graph analysis. But the low flexibility and high complexity of API are problems of these solutions. A linear algebra based model, formalized in GraphBLAS [3], provides a user-friendly API. While the reference CPU-based implementation for this API, SuiteSparse [4], demonstrates good performance on real-world tasks, GPU-based implementation is challenging due to required operations generalization, data sparsity, and hardware programming complexity. Such well-known libraries as cuSPARSE, clSPARSE, bhSPARSE cannot be reused, since almost all of them are specified for operations over floats. GraphBLAST [5] and GBTL [6] show promising GPU performance of GraphBLAS-based graph analysis solutions. But these solutions are not portable because they are based on Nvidia Cuda. Portable solution is a challenge due to intricate GPU programming. To address this problem, we developed the GraphBLAS-inspired *Spla*[1] library, which features portable OpenCL-based acceleration and shows performance comparable with GraphBLAST, achieving speedup of up to 36 times.

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[1]Source code and project page: github.com/SparseLinearAlgebra/spla

II. Proposed Solution

The proposed Spla library implemented using the C++17 language and vendor-agnostic OpenCL 1.2 for GPU specific computations. The OpenCL is chosen over Cuda and SyCL technologies. While Cuda is specific only for Nvidia devices, SyCL is a promising API, but it is too high-level and its support is still controversial. The implementation of common operations and graph algorithms is based on papers [5], [7], [8] of Yang et al. It involves such optimizations as push-pull, masking, early exit, and sparse-dense storage switch. Also Spla features a number of nontrivial OpenCL-specific improvements, such as custom small memory allocation, kernel cache, and operations storage to reduce overall CPU-driver overhead.

III. Evaluation

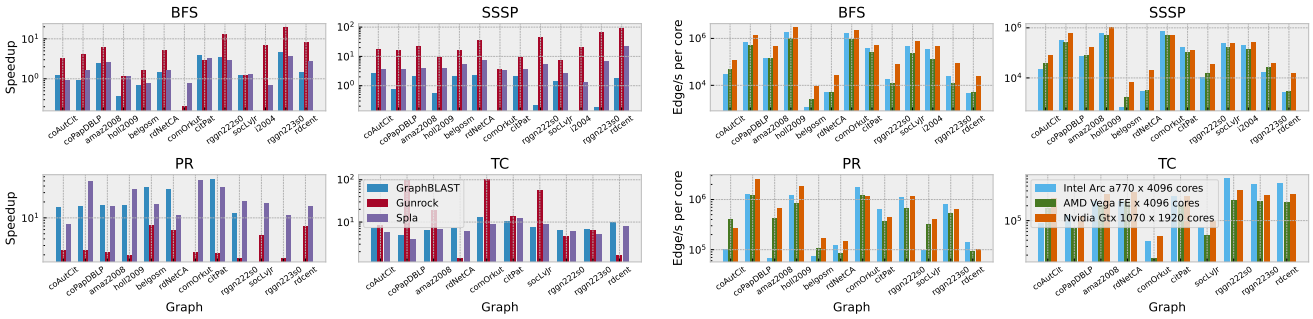
For performance analysis of the proposed solution, we evaluated a few most common graph algorithms, such as BFS, SSSP, PR and TC, using real-world sparse matrix data. As a baseline for the comparison we chose LAGraph [9] in connection with SuiteSparse [4] as a multi-core CPU tool and Gunrock [2] and GraphBLAST [5] as a Nvidia GPU tools. Also, we tested algorithms on several devices with distinct OpenCL vendors in order to validate the portability of the proposed solution.

TABLE I: Dataset description.

Graph	Vertices	Edges	Out Degree		
			Avg	Sd	Max
coAuthorsCit	227.3K	1.6M	7.2	10.6	1.4K
coPapersDBLP	540.5K	30.5M	56.4	66.2	3.3K
amazon2008	735.3K	7.0M	9.6	7.6	1.1K
hollywood2009	1.1M	112.8M	98.9	271.9	11.5K
comOrkut	3.1M	234.4M	76.3	154.8	33.3K
citPatents	3.8M	33.0M	8.8	10.5	793.0
socLiveJournal	4.8M	85.7M	17.7	52.0	20.3K
indochina2004	7.4M	302.0M	40.7	329.6	256.4K
belgiumosm	1.4M	3.1M	2.2	0.5	10.0
roadNetCA	2.0M	5.5M	2.8	1.0	12.0
rggn222s0	4.2M	60.7M	14.5	3.8	36.0
rggn223s0	8.4M	127.0M	15.1	3.9	40.0
roadcentral	14.1M	33.9M	2.4	0.9	8.0

A. Evaluation Setup

We use a PC with Ubuntu 20.04 installed, which has 3.40Hz Intel Core i7-6700 4-core CPU, DDR4 64Gb RAM, either



(a) GPU tools on the Nvidia device, speedup relative to LaGraph

(b) Spla on different devices, edge/s throughput per device core

Fig. 1: Performance analysis. Logarithmic scale is used. Bar not shown if tested tool failed due to out-of-memory exception.

Nvidia GeForce GTX 1070 8Gb VRAM, Intel Arc A770 flux 8GB VRAM or AMD Radeon Vega Frontier Edition, 16GB VRAM. Programs were compiled with GCC v9.4. Programs that use Cuda were compiled with GCC v8.4 and Nvidia NVCC v10.1. Data loading time, preparation, format transformations, and host-device initial communications are excluded from time measurements. All tests are averaged across 10 runs. The deviation of measurements does not exceed the threshold of 10 percent. The additional warm-up run is excluded from measurements. The first graph vertex is the initial node in traversal algorithms.

Thirteen matrices with graph data were selected from the Sparse Matrix Collection at University of Florida [10]. The dataset is described in Table I. All graphs are converted to undirected. Self-loops and duplicated edges are removed. The weights are generated using uniform distribution $[0, 1]$ of floating-point values.

B. Results Summary

RQ1. *How does the performance of the proposed solution compare with existing tools for GPU analysis?* Taking a look at Fig. 1a, Spla shows acceptable performance in all algorithms, running with comparable speed to its nearest competitor, GraphBLAST, outperforming it up to 36 times in some cases. Also the proposed library does not suffer from memory issues on some large graphs. Spla is consistently several times faster than LaGraph, achieving speedup of up to 25 times in extreme cases. Gunrock is the fastest GPU framework for analysis. It dominates the overall performance and only falls short on the PR algorithm evaluation.

RQ2. *What is the performance of the proposed solution on various devices vendors and OpenCL runtimes?* Spla successfully launches and works on the GPU of distinct vendors, including Intel, AMD and Nvidia. It shows promising performance and demonstrates scalability in relation to the number of computing cores. Fig. 1b depicts the edge per second throughput per a GPU core for all devices. These metrics are quite predictable for the same graphs. This can be seen if one takes into account the overall shape of the figures for BFS, SSSP, PR and TC as a whole.

IV. Conclusion

We presented Spla, the generalized sparse linear algebra library with vendor-agnostic GPUs accelerated computations. The evaluation of the proposed solution for some real-world graphs on four different algorithms shows, that the OpenCL-based solution demonstrates competitive performance and has acceptable scalability on devices of different GPUs vendors. There is still a plenty of research questions and directions for improvement, such as further workload balance, performance tuning, graph streaming [1] and multi-GPU support [2].

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