Introduction to GraphBLAS

Tools and resources

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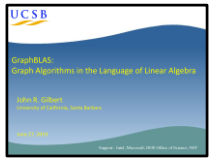
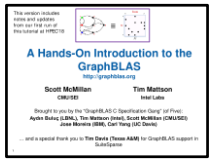
Further reading and libraries

RESOURCES

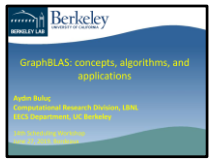
Presentations and tutorials for learning GraphBLAS along with a link to a collection of pointers.



J.R. Gilbert:
GraphBLAS: Graph Algorithms in the Language of Linear Algebra, Seminar talk since 2014



S. McMillan and T.G. Mattson:
A Hands-On Introduction to the GraphBLAS, Tutorial at HPEC since 2018



A. Buluç:
GraphBLAS: Concepts, algorithms, and applications, Scheduling Workshop, 2019

M. Kumar, J.E. Moreira, P. Pattnaik:
GraphBLAS: Handling performance concerns in large graph analytics,
Computing Frontiers 2018

List of GraphBLAS-related books, papers, presentations, posters, software, etc.
[szarnyasg/graphblas-pointers]

THE LAGRAPH LIBRARY

- Similar to the LAPACK library for BLAS
- Uses SuiteSparse:GraphBLAS
- Implementations of common algorithms
  - BFS, SSSP, LCC, PageRank, Boruvka
  - Triangle count, k-truss
  - CDLP (community detection using label propagation)
  - Weakly connected components, Strongly Conn. Comps (draft)
  - Betweenness centrality
  - Deep neural network

T.G. Mattson et al.: *LAGraph: A Community Effort to Collect Graph Algorithms Built on Top of the GraphBLAS,* GrAPL@IPDPS 2019

GraphBLAS/LAGraph

REQUIREMENTS BY GRAPH COMPUTATIONS

Libraries for linear-algebra based graph processing support the following features (prioritized):

1. Sparse matrices	For reasonable performance
2. Arbitrary semirings	For expressive power
3. Masking	A big reduction in complexity for some algos
4. Parallel execution	Constant speedup, ideally by #threads

Most libraries **only satisfy requirement #1:** Intel MKL, Eigen, Boost uBLAS, MTL4, Armadillo, NIST Sparse BLAS, GMM++, CUSP, Numpy

Exceptions are the Efficient Java Matrix Library (EJML) and Julia's `SparseArrays` library, where arbitrary semirings can be used.

GRAPHBLAS PAPERS AND BOOKS

- *Standards for Graph Algorithm Primitives*
  - Position paper by 19 authors @ IEEE HPEC 2013

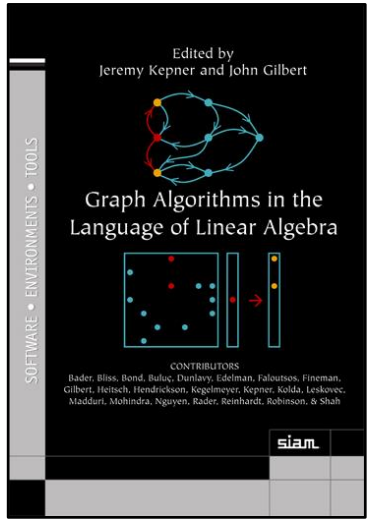
- *Novel Algebras for Advanced Analytics in Julia*
  - Technical paper on semirings in Julia @ IEEE HPEC 2013

- *Mathematical Foundations of the GraphBLAS*
  - Theory paper by 16 authors @ IEEE HPEC 2016

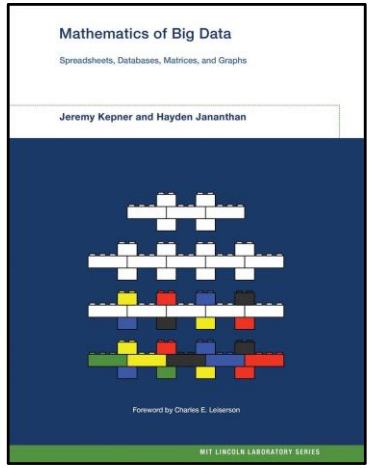
- *Design of the GraphBLAS C API*
  - Design decisions and overview of the C API @ GABB@IPDPS 2017

- *Algorithm 1000: SuiteSparse:GraphBLAS: graph algorithms in the language of sparse linear algebra*
  - Algorithms in the SuiteSparse implementation @ ACM TOMS 2019

BOOKS



- *Graph Algorithms in the Language of Linear Algebra*
  - Edited by J. Kepner and J.R. Gilbert, published by SIAM in 2011
  - Algorithms for connected components, shortest paths, max-flow, betwenness centrality, spanning tree, graph generation, etc.
  - Algorithms and data structure for fast matrix multiplication
  - Predates GraphBLAS: preliminary notation, no API usage



- *Mathematics of Big Data*
  - Authored by Jananthan & Kepner, published by MIT Press in 2018
  - Generalizes the semiring-based approach for associative arrays
  - Contains reprints of papers, including the HPEC'16 paper above
  - Discusses D4M (Dynamic Distributed Dimensional Data Model)

GRAPHBLAS COMMUNITY

Wiki: graphblas.org | **Communication:** mailing list, monthly telcos

Annual events:

- May: IEEE IPDPS conference
  - GrAPL workshop (Graphs, Architectures, Programming and Learning), a merger of
    - GABB (Graph Algorithms Building Blocks)
    - GraML (Graph Algorithms and Machine Learning)
  - See graphanalysis.org for previous editions
- Sep: IEEE HPEC conference
  - GraphBLAS BoF meeting
- Nov: IEEE/ACM Supercomputing conference
  - GraphBLAS Working Group
  - IA^3 workshop (Workshop on Irregular Applications: Architectures and Algorithms)

Blog: AldenMath by Timothy Alden Davis

REDISGRAPH

- Graph database built on top of Redis with partial (but extending) support for the Cypher language
- Uses SuiteSparse:GraphBLAS for graph operations
- Preliminary benchmark results show good performance on traversal-heavy workloads

R. Lipman, T.A. Davis:
Graph Algebra – Graph operations in the language of linear algebra
RedisConf 2018

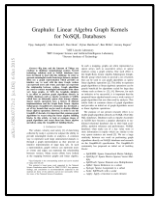
R. Lipman:
RedisGraph internals
RedisConf 2019

GRAPHBLAS IMPLEMENTATIONS

- SuiteSparse:GraphBLAS
  - v1.0.0: Nov 2017 – sequential
  - v3.0.1: July 2019 – parallel
  - v4.0.0: WIP – bitmap representation
- IBM GraphBLAS
  - Complete implementation in C++, released in May 2018
  - Concise but sequential
- GBTL (GraphBLAS Template Library): C++
  - v1.0: parallel but no longer maintained
  - v2.0, v3.0: sequential
- GraphBLAST: GPU implementation, based on GBTL

GRAPHULO

- Build on top of the Accumulo distributed key-value store
- Written in Java
- Focus on scalability



V. Gadepally et al.:
Graphulo: Linear Algebra Graph Kernels for NoSQL Databases, GABB@IPDPS 2015

COMBBLAS: COMBINATORIAL BLAS

- “an extensible distributed memory parallel graph library offering a small but powerful set of linear algebra primitives”
- Not a GraphBLAS implementation but serves as an incubator for new ideas that may later find their way into GraphBLAS
- Scales to 250k+ CPU cores
  - Used on supercomputers such as Cray

A. Buluç, J.R. Gilbert: *The Combinatorial BLAS: design, implementation, and application,* International Journal of High Performance Computing Applications, 2011

Learning GraphBLAS

LEARNING GRAPHBLAS

- Challenging to get started – need to have an understanding of:
  - Linear algebra (semirings, matrix multiplication, etc.)
  - Connection between linear algebra and graph operations (intuition)
  - Sizeable C API
- 200+ slides presenting algorithms in GraphBLAS
  - BFS variants, PageRank, Triangle count, k-truss
  - Community detection using label propagation
  - Luby's maximal independent set algorithm
  - computing connected components on an overlay graph
  - etc.

PYGRAPHBLAS: PYTHON WRAPPER #1

- A Python wrapper
- See example code for SSSP and triangle count
- Close to pseudo-code
- Jupyter support

```
def sssp(matrix, start):
    v = Vector.from_type(matrix.gb_type, matrix.nrows)
    v[start] = 0

    with min_plus, Accum(min_int64):
        for _ in range(matrix.nrows):
            w = Vector.dup(v)
            v @= matrix
            if w == v:
                break
        return v
```

```
def sandia(A, L):
    return L.mxm(L, mask=L).reduce_int()

sandia(M, M.tril())
```

Added benefit: both Python and GraphBLAS use 0-based indexing

michelp/pygraphblas

GRBLAS: PYTHON WRAPPER #2

- Goal: one-to-one mapping of the GraphBLAS API
  - less Pythonic
  - comes with a Conda package
  - compiles user-defined functions to C

jim22k/grblas

Tradeoffs

TRADEOFFS OF GRAPHBLAS

- Challenging to get started – need to have an understanding of:
  - Linear algebra (semirings, matrix multiplication, etc.)
  - Connection between linear algebra and graph operations
  - The GraphBLAS C API
- Some additional building blocks required
  - Sorting
  - Permutation
  - Dynamically-sized values (e.g. to store paths)
- Currently the only high-performance CPU implementation is SuiteSparse:GraphBLAS
  - Written in C11
  - Some features (e.g. the `_Generic` macro) are incompatible with C++.

TRADEOFFS OF GRAPHBLAS

- Updating CSR/CSC matrices is slow
  - SuiteSparse mitigates this to some extent by allowing incremental build before using the matrix but it still needs to rebuild the matrix before major operations such as mxv, mxm
  - But: GraphBLAS objects are opaque and alternative formats can be used
    - Hornet [HPEC'18]
    - faimGraph [SC'18]
    - STINGER [HPEC'12]