BLAStoff

Graph computation language based on the BLAS* specification

*Basic Linear Algebra Subprograms

Let’s hop right in

01 Motivation

02 Semirings

03 Selection

04 Other features

05 Dirty Details

06 Demo

Motivation

Graphs as matrices

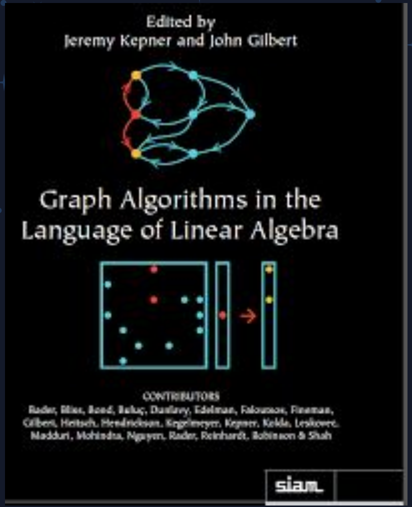
Graphs can be represented as matrices.

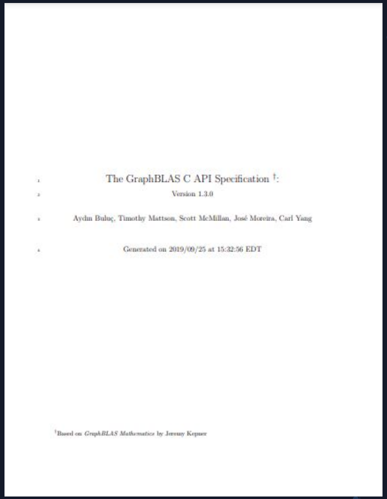
Graph operations can be written as matrix operations.

Benefits

Matrix operations are highly optimized, fully realizing parallel computation.

GraphBLAS API





The GraphBLAS C API Specification †:

Version 1.3.0

Aydın Buluç, Timothy Mattson, Scott McMillan, José Moreira, Carl Yang

Generated on 2019/09/25 at 15:32:56 EDT

†Based on *GraphBLAS Mathematics* by Jeremy Kepner

BFS using the C GraphBLAS Library

```c
#include <stdlib.h>
#include <stdio.h>
#include <stdint.h>
#include <stdbool.h>
#include "GraphBLAS.h"

/*
 * Given a boolean n x n adjacency matrix A and a source vertex s, performs a BFS traversal
 * of the graph and sets v[i] to the level in which vertex i is visited (v[s] == 1).
 * If i is not reacheable from s, then v[i] = 0. (Vector v should be empty on input.)
 */
GrB_Info BFS(GrB_Vector *v, GrB_Matrix A, GrB_Index s)
{
  GrB_Index n;
  GrB_Matrix_nrows(&n,A);                          // n = # of rows of A

  GrB_Vector_new(v,GrB_INT32,n);                   // Vector<int32_t> v(n)

  GrB_Vector q;                                    // vertices visited in each level
  GrB_Vector_new(&q,GrB_BOOL,n);                   // Vector<bool> q(n)
  GrB_Vector_setElement(q,(bool)true,s);           // q[s] = true, false everywhere else

  /*
   * BFS traversal and label the vertices.
   */
  int32_t d = 0;                                   // d = level in BFS traversal
  bool succ = false;                               // succ == true when some successor found
  do {
    ++d;                                           // next level (start with 1)
    GrB_assign(*v,q,GrB_NULL,d,GrB_ALL,n,GrB_NULL);    // v[q] = d
    GrB_vxm(q,*v,GrB_NULL,GrB_LOR_LAND_SEMIRING_BOOL,
            q,A,GrB_DESC_RC);                      // q[!v] = q ||.&& A ; finds all the
                                                   // unvisited successors from current q
    GrB_reduce(&succ,GrB_NULL,GrB_LOR_MONOID_BOOL,
               q,GrB_NULL);                        // succ = ||(q)
  } while (succ);                                  // if there is no successor in q, we are done.

  GrB_free(&q);                                    // q vector no longer needed

  return GrB_SUCCESS;
}
```

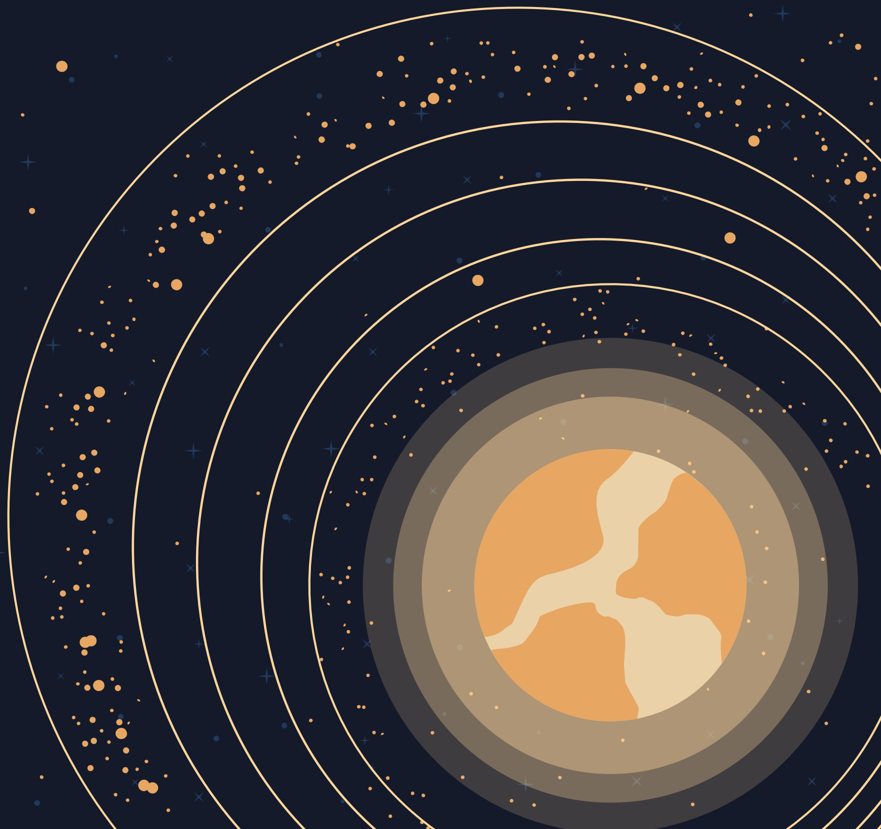
Can we do better?

From “The GraphBLAS C API Specification”, Buluç, et al

BFS in BLAStoff

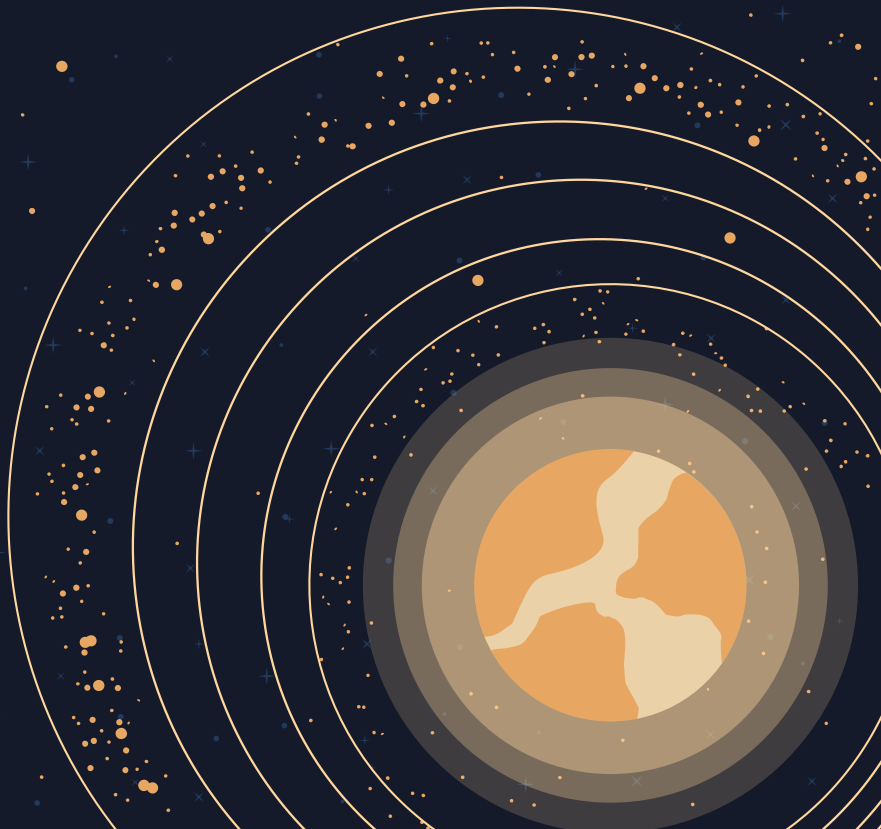
```
def BFS(G, frontier) {
    #logical;
    N = |G|[0];
    levels = Zero(N : 1);
    maskedGT = G^T;
    depth = 0;
    while (plusColumnReduce(frontier)) {
        #arithmetic;
        depth = depth + 1;
        #logical;
        levels[rangeFromVector(frontier)] = depth;
        mask = !(levels)[0, Zero(N:1), N, 1];
        maskedGT = maskedGT @ mask;
        frontier = maskedGT * frontier;
    }
    #arithmetic;
    return levels + One(|levels|)~(-1);
}
```

There's a lot going on here. Let's talk about some of these features!



BLAStoff Overview

- Every object is a matrix
- Imperative
- Wide offering of primitive matrix operations
- Versatile matrix selection operator
- Semiring semantics



What is a **semiring?**

A set of two binary operators: addition and multiplication.

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- (R, +) is a commutative monoid with identity element 0
- (R, *) is a monoid with identity element 1
- Multiplication left and right distributes over addition
- Multiplication by 0 annihilates R

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Arithmetic semiring:

- 3 + 7 = 10
- 3 * 7 = 21
- etc.

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- 3 + 0 = 1
- 3 + 7 = 1
- 0 + 0 = 0
- 3 * 0 = 0
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Arithmetic semiring:

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- etc.

Logical semiring:

- 3 + 0 = 1
- 3 + 7 = 1
- 0 + 0 = 0
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- etc.

Maxmin semiring:

- 3 + 7 = 7
- 3 * 7 = 3
- etc.

Semirings in BLAStoff

`#semiring-name;` to change semiring

Semirings in BLAStoff

`#semiring-name;` to change semiring

```
A = [ 1, 2;
      3, 4  ];

B = [ 0, -1;
     -2,  5 ];

#maxmin;
printm(A + B);   // prints:  1 2\n3 5
printm(A * B);   // prints: -2 2\n-2 4

#arithmetic;
printm(A + B);   // prints:  1 1\n1 9
printm(A * B);   // prints: -4 9\n-8 17
```

Semirings in BLAStoff

```
def addThree(A, B, C) {
    sum = A + B + C;
    return sum;
}

def f(A, B, C) {
    #maxmin;
    printm(addThree(A, B, C));  // prints 6
    printm(A + B + C);          // prints 3
}

A = 1;
B = 2;
C = 3;

printm(A + B + C);  // prints 6
f(A, B, C);
```

Semirings in BLAStoff

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Semirings in BLAStoff

```
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    #_;
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A = 1;
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```

03

Selection

“There is wisdom in the **selection** of wisdom.”

– **Dr. Bergen Evans**, English professor and TV host

How should selection work?

- Robust
- Expressive
- Powerful
- But **concise**
- In other words, matrix.get(i,j) won't cut it

Our selection operator

- M[A, B, c, d]
- A: row indices, B: column indices
- c, d: size of the submatrices
- A is the only required argument
- B, c, d default to [0], [1], [1], respectively

Example

```
v = [1;2;3;4];
M = [1, 2, 3;
     4, 5, 6;
     7, 8, 9];

v[2]; // gets [3]
M[2,1]; // gets [8]
v[[0;3]]; // gets [1;4]
M[1, 1, 1, 2]; // gets [5,6]
```

Example

row indices

column indices

size

```
M = [1, 2, 3;
     4, 5, 6;
     7, 8, 9];

M[[1;0], [0;1], 2, 2];

/* gets:
[4, 5, 5, 6;
 7, 8, 8, 9;
 1, 2, 2, 3;
 4, 5, 5, 6;]*/
```

Example

row indices

column indices

size

```
M = [1, 2, 3;
     4, 5, 6;
     7, 8, 9];

M[[1;0], [0;1], 2, 2];

/* gets:
[4, 5, 5, 6;
 7, 8, 8, 9;
 1, 2, 2, 3;
 4, 5, 5, 6;]*/
```

Example

```
M = [1, 2, 3;
          4, 5, 6;
          7, 8, 9];

M[0, [0;2], 2, 1] = [-1;-1];

/* sets M to
[-1, 2, -1;
 -1, 5, -1;
 7, 8, 9];*/
```

04

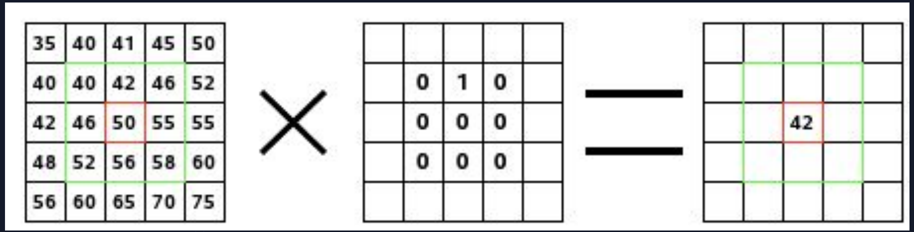
Operators

“It's not the **operation** itself that is the concern, it's the anesthesia.”

– **Sanjay Gupta**, neurosurgeon

Convolution ~

A ~ B: slide B across A like so…



…where each windowed view becomes just one entry in the resulting matrix.

Why is this useful for us?

Convolution ~

- Can be used to emulate other typical operators, most notably scalar multiplication.
- BLAStoff has no scalars. To achieve this, we just use a sliding window of size 1x1!

```
A = [1, 2, 3; 4, 5, 6];
k = 2;
B = A ~ k;
// B is now [2, 4, 6; 8, 10, 12];
```

Size | |

- For an m x n matrix A, |A| returns a 2 x 1 column vector with values m and n.
- For instance, to make an m x n matrix of zeros would simply be:

```
A = [1, 2, 3; 4, 5, 6];
B = Zero(|A|);

// B is now [0, 0, 0; 0, 0, 0];
```

Size | |: Nifty Example

If we isolate the values into separate variables, we can use selection to replace all values of A!

```
m = |A|[0];
n = |A|[1];

A[range(m), range(n)] = 3;
```

Reduce Rows %

Row-reductions with either summation or product.

```
A = [1, 2; 3, 4];
B = +%A; // B is [3; 7]
C = *%A; // C is [2; 12]
```

(And this works with semirings!!)

Another Feature: Graph Literals

Graphs can be declared just like matrices

```
// These create equivalent matrices
G = [ 0->1; 2->3; 3->0 ]
M = [ 0,1,0,0;
      0,0,0,1;
      0,0,0,0;
      1,0,0,0 ]
```

Other basic operators

- Matrix multiplication (*)
- Element-wise multiplication (@) and addition (+)
- Exponent: ^(b | T) where b is a 1x1 matrix and b ≥ 0
- Vertical concatenation (:)

05

Dirty details;
Are we proud?

What We're Proud Of

01 Our Process

- Excellent division of labor, everyone specialized while still interacting with all the code
- Github issues for feature tracking

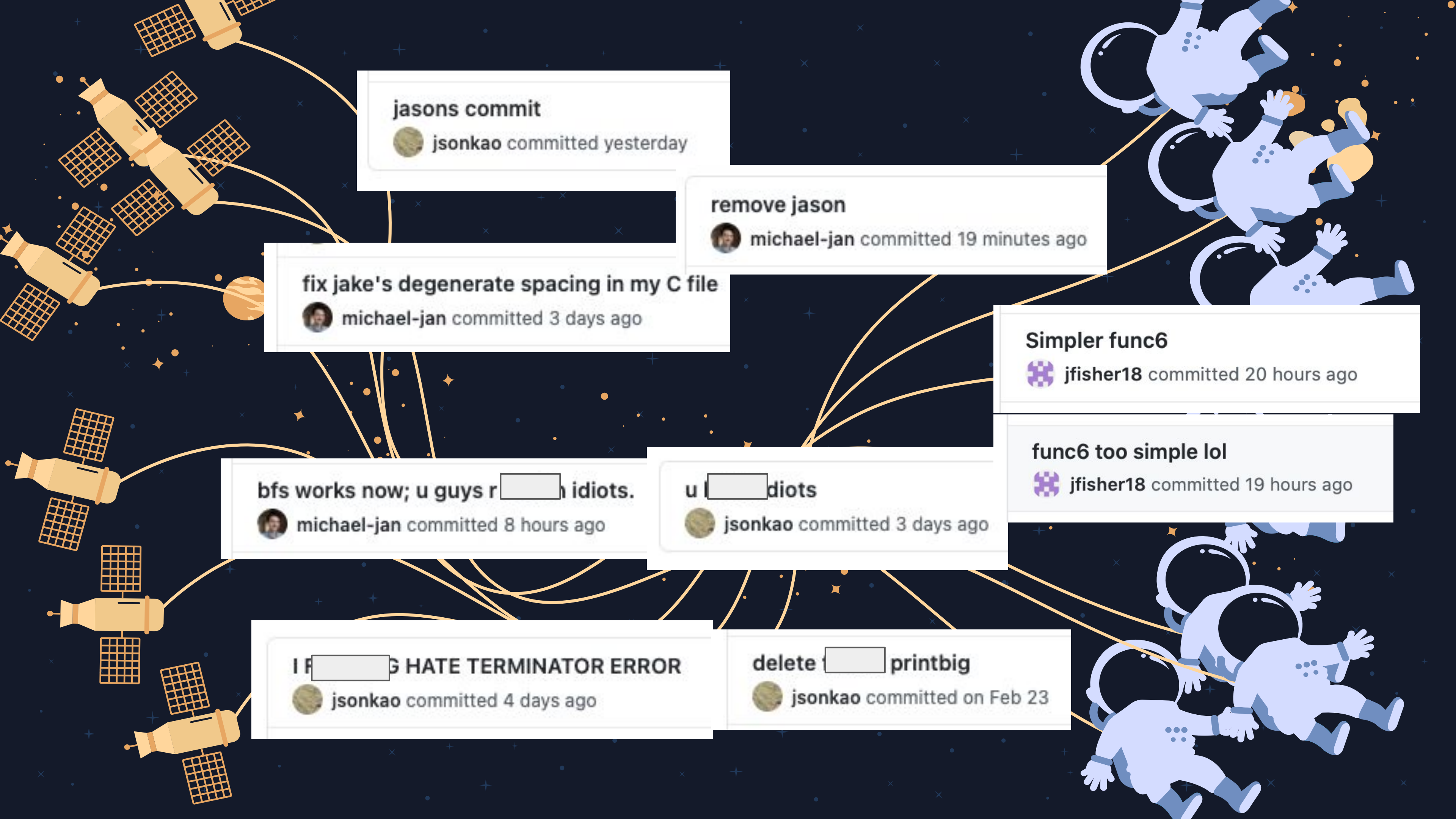
02 Our Project

- Implemented our full LRM, save stretch goals
- Learned linear algebra and abstract algebra

03 Our Code

- Removed SAST while keeping type-checking of int vs float matrices
- Programmatically created function types, definitions, and calls
- Lazy evaluation
- Semiring stack

What We’re Not Proud Of:
Our commit messages


jasons commit
jsonkao committed yesterday
remove jason
michael-jan committed 19 minutes ago
fix jake's degenerate spacing in my C file
michael-jan committed 3 days ago
Simpler func6
jfisher18 committed 20 hours ago
func6 too simple lol
jfisher18 committed 19 hours ago
bfs works now; u guys r h idiots.
michael-jan committed 8 hours ago
u l diots
jsonkao committed 3 days ago
I F G HATE TERMINATOR ERROR
jsonkao committed 4 days ago
delete t printbig
jsonkao committed on Feb 23

BFS Demo

Questions?

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