A Distributed Multi-GPU System for Fast Graph Processing

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What is Lux? / Contributions of paper

Computational Model:

- 2 execution models
- A dynamic repartitioning strategy
- A performance model for parameter choice

Implementation:

- Working code
- Benchmarked on different algorithms
- Comparisons to different platforms

Motivation / Prior Work

- Lux: A graph processing framework to run on multi-GPU clusters
- Prior work for:
  - Single-node CPU
  - Distributed CPU
  - Single-node GPU
- Prior work cannot be adapted easily to GPU clusters
  - Data placement (heterogeneous memories)
  - Optimisation interference
  - Load-balancing does not map across from CPUs

Abstraction

- Iteratively modifies subset of graph until convergence
- Edges and vertices have properties
- 3 stateless functions to implement:
  - `void init(Vertex v, Vertex` v^{old}`)`
  - `void compute(Vertex v, Vertex` u^{old}`, Edge e)`
  - `bool update(Vertex v, Vertex` v^{old}`)`

Abstraction: Pull vs Push

Algorithm 1 Pseudocode for generic pull-based execution.

```
while not halt do
    halt = true                                   ▷ halt is a global variable
    for all v ∈ V do in parallel
        init(v, v^old)
        for all u ∈ N^−(v) do in parallel
            compute(v, u^old, (u, v))
        end for
        if update(v, v^old) then
            halt = false
        end if
    end for
end while
```

- Does not require additional synchronisation
- Takes advantage of GPU caching and aggregation

Algorithm 2 Pseudocode for generic push-based execution.

```
while F ≠ {} do
    for all v ∈ V do in parallel
        init(v, v^old)
    end for
                                                  ▷ synchronize(V)
    for all u ∈ F do in parallel
        for all v ∈ N^+(u) do in parallel
            compute(v, u^old, (u, v))
        end for
    end for
                                                  ▷ synchronize(V)
    F = {}
    for all v ∈ V do in parallel
        if update(v, v^old) then
            F = F ∪ {v}
        end if
    end for
end while
```

- Better for rapidly changing frontiers

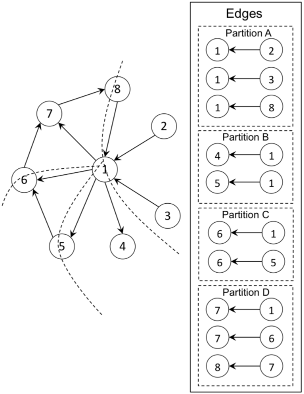
Task Execution

- Pull-based:
  - Single GPU kernel for all steps
  - Scan-based gather to resolve load imbalance
- Push-based:
  - Separate kernel for all 3 steps
  - All updates have to use device memory to avoid races
- Computation can overflow to CPU+DRAM if not enough space

Graph Partitioning

Lux uses Edge partitioning

- Idea: Assign equal number of edges to each partition
- Each partition holds contiguously numbered vertices and the edges pointing to them
- So GPU can coalesce reads and writes to consecutive memory
- Very fast to compute (e.g. vs vertex-cut)



Dynamic Repartitioning

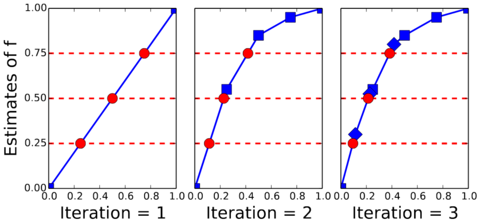
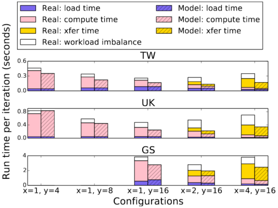


Figure: Estimates of $f(x) = \sum_{i=0}^{x} w_i$ used to pick pivot vertices.

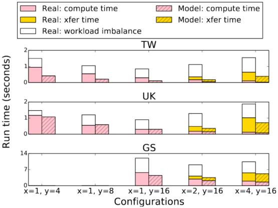
1. Collect t_i per P_i, update f, calculate partitioning
2. Compare $\Delta_{gain}(G)$ (improvement) vs $\Delta_{cost}(G)$ (inter-node transfer)
3. Globally repartition depending on 2
4. Local repartition

Performance Model

- To preselect an execution model and runtime configuration
- Models performance for a single iteration
- Sums together estimates for:
  1. Load time
  2. Compute time
  3. Update time
  4. Inter-node transfer time



(a) Pull-based executions (PR).



(b) Push-based executions (CC).

Evaluation

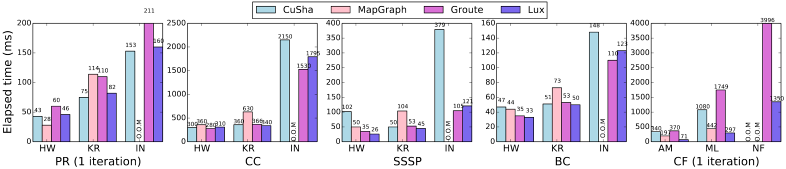


Figure 15: Performance comparison on a single GPU (lower is better).

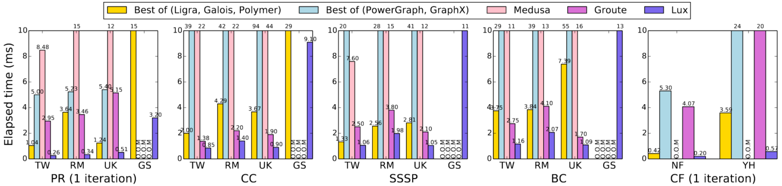


Figure 16: The execution time for different graph processing frameworks (lower is better).

Different hardware used for shared memory and GPU testing.
Tried to get best attainable performance from every system.

Criticisms

- Abstract claims up to 20x speedup over shared-memory systems (more like 5-10)
- “Most popular graph algorithms can be expressed in Lux” Does not assess what cannot be.
- “For many applications … identical implementation for both push and pull”
- Did not test the overflow processing to CPU feature
- For evaluation all parameters were highly tuned. Can’t guarantee others were as tuned as Lux.