ACM SIGMOD Programming Contest 2016

Team: gStreamPKU

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1. Task Description

The task is to solve the **shortest path problem** on a **dynamic graph** with directed but unweighted edges. Firstly the test harness sends the initial graph. The time spent on loading, pre-processing or indexing the initial graph will not count into the total execution time.

Then the workload comes in batches. Each batch consists of three types of operations:

(1) *A u v* -- add an edge from vertex *u* to *v*.

(2) *D u v* -- delete the edge from *u* to *v*, if it exists.

(3) *Q u v* -- query the distance of the shortest path from *u* to *v*.

Our goal is to answer these queries correctly, and as quickly as possible.

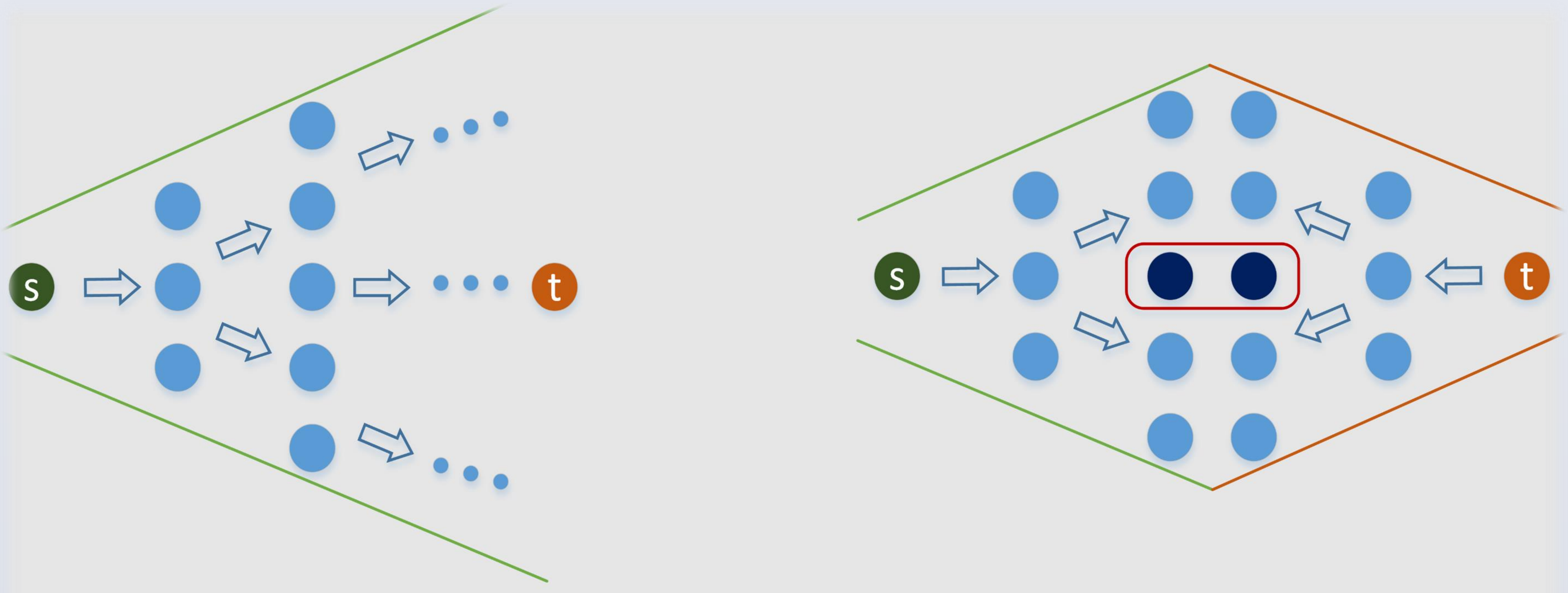
2. Solution Overview

We have tried to improve the performance from the following aspects:

- Reduce the overall search space for each query: Bidirectional-BFS.
- Reduce the number of basic operations per query: Bit Compression and Optimizing program's spatial locality.
- Develop parallelism: Build Delta Graph to support fully concurrent query execution within a batch.

3. Bidirectional-BFS

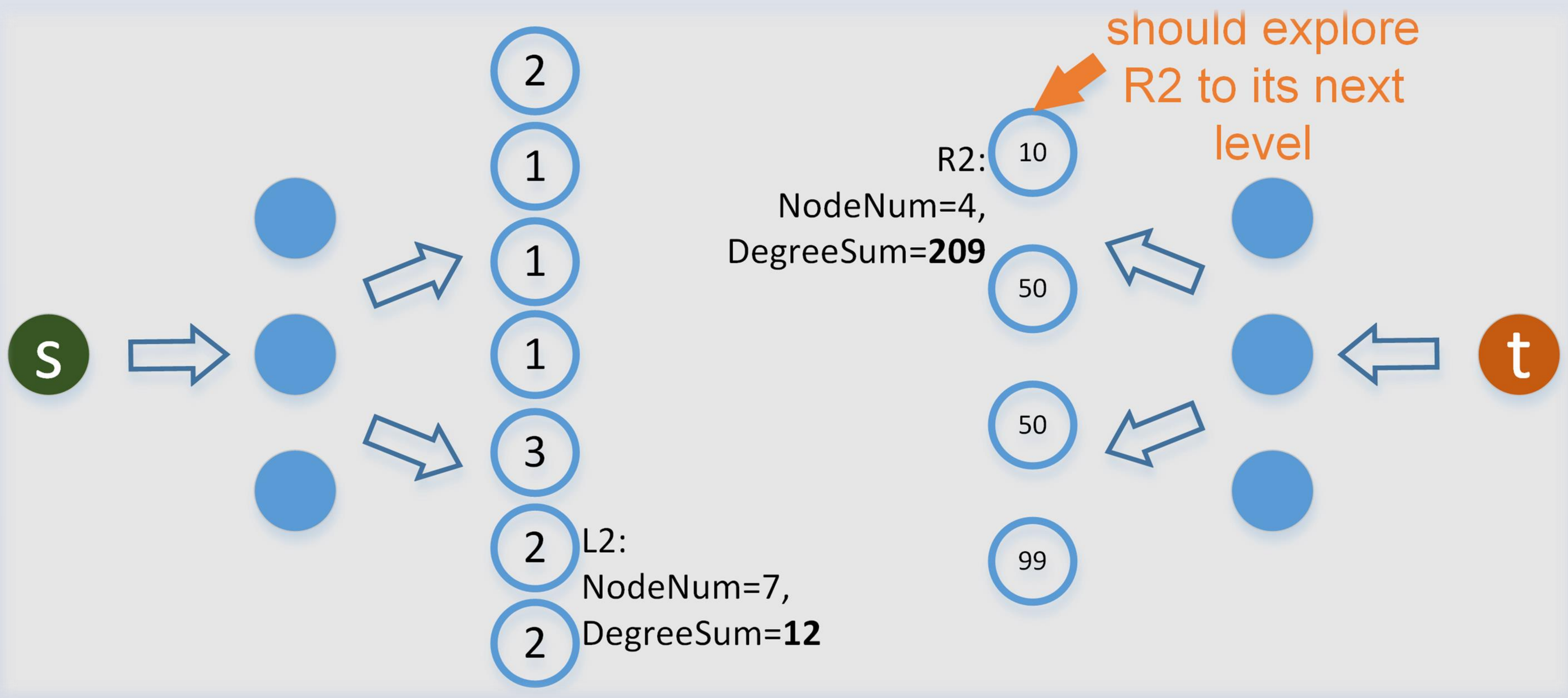
Bidirectional-BFS instead of naïve BFS: To reduce the search space of each query, we search from both forward direction and backward direction.



Naïve BFS

Bidirectional BFS

Decision-making of exploration direction : At each iteration, we select the direction of smaller sum of degrees to explore first.

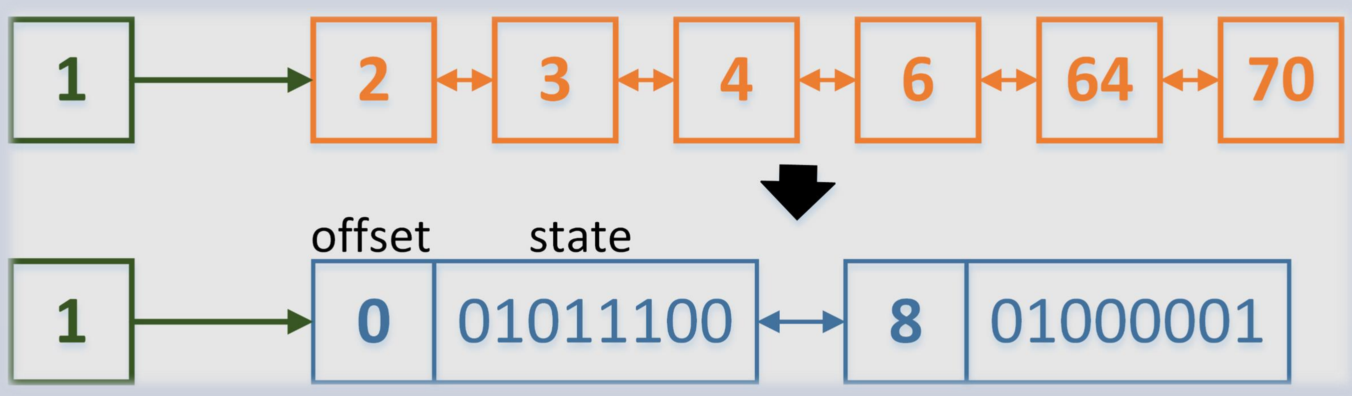


Trick: We calculate the initial graph's degree variance offline. If the degree variance is small(implies $DegreeSum \propto NodeNum$, e.g. roadmap graph), we can use $NodeNum$ to save $DegreeSum$'s online computing cost.

4. Edge List's Bit Compression

Compression of adjacent edge list: offset field + state field

- Reduce space cost(however we do not care). In best case, $M' = M/8$ (for 64-bit integer, $M/64$).
- Reduce query's execution time cost. Because we also maintain the visited vertex set in this compression format during Bidirectional-BFS.



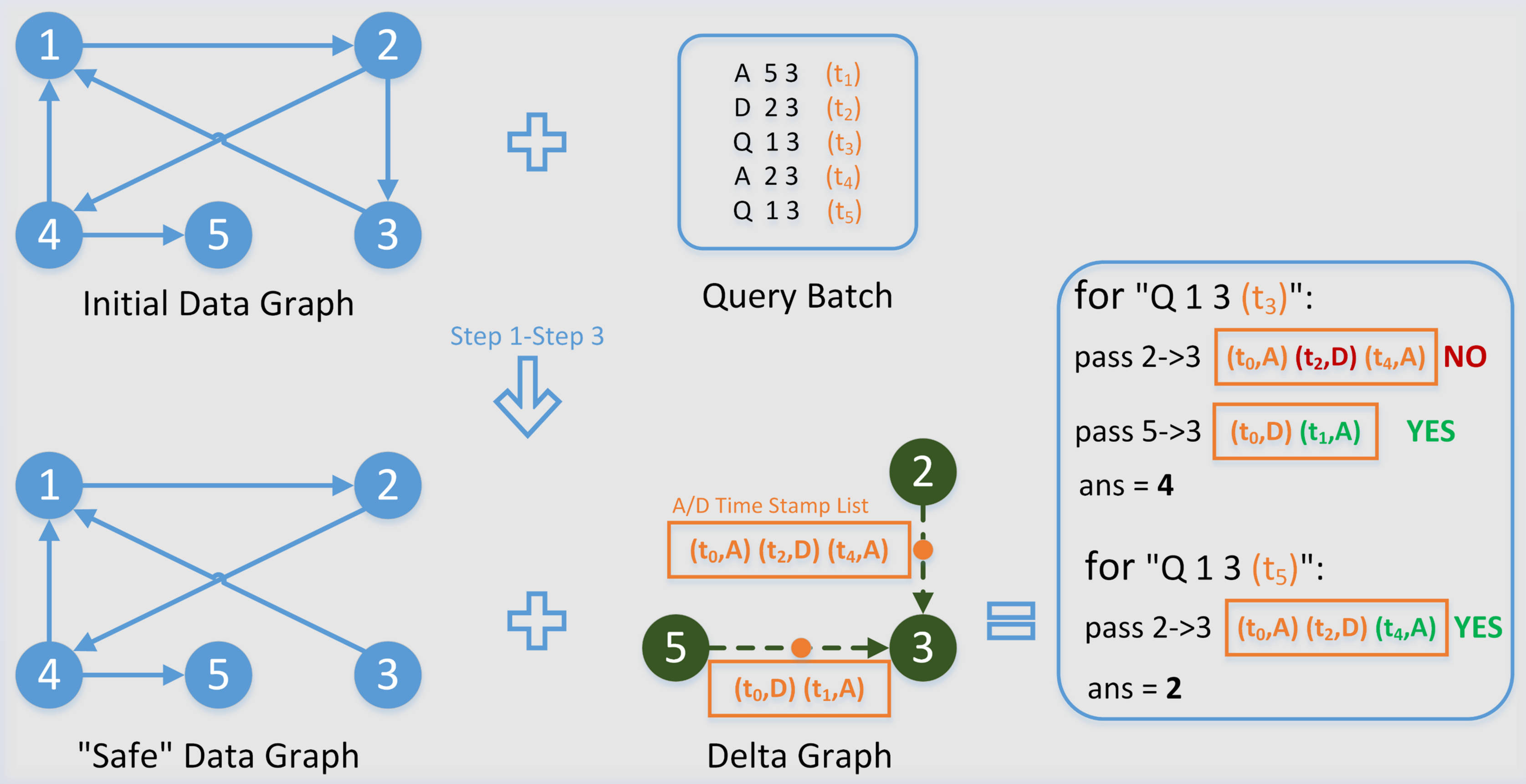
- In worst case, $M' = M(comp\_ratio = 1.0)$. For example, vertex 1 has forward neighbor vertices {64, 128, 192, 256}. It also needs four 64-bit integer to store the state fields.
- Here we propose an open question: Find a vertex ID reassignment function(a bijection from N to N) that minimize $comp\_ratio$.
- In our implementation, we adopt a greedy strategy:
  - Step 1: Sort vertices by their backward edge degree in descending order in V_d.
  - Step 2: Enumerate vertex v in V_d in order, and assign new ID continuously for v's backward neighbor vertices.

Note: Through the bit compression technique, vertices with large degree can be explored more efficiently, because we can process its neighbors once a batch when they are compressed into one 64-bit integer. Therefore, this technique improves performance significantly for social network graphs and paper-citation network graphs.

5. Fully Concurrent Query Execution Mechanism

Delta Graph: When processing a batch, we maintain a Delta Graph over all the A/D operations. The Delta Graph preserves not only updated edges in this batch, but also each edge's *A/D time stamp list* in order.

For example, if the edge $e(v_2, v_3)$ is deleted at time t_2, and added back at time t_4, then its time stamps are (t_2, D) and (t_4, A). Furthermore, if an edge already exists in the version of graph before this batch, we add (t_0, A) to the head of its time stamp list. Otherwise, we add (t_0, D). Finally its A/D time stamp list is $[(t_0, A), (t_2, D), (t_4, A)]$.



Steps of processing a batch:

- S1: Read in this batch's operation list.
- S2: Build Delta Graph over A/D operations.
- S3: Delete edges of D operations in Data Graph. Therefore, all the rest edges in Data Graph can be explored "safely" within this batch's queries.
- S4: Execute all queries concurrently on "Safe" Data Graph + Delta Graph.
- S5: Output answers sequentially.
- S6: Add edges of A operations to Data Graph.

6. Optimizing Spatial Locality

- **Rearrange graph's storage in memory:** Neighbor vertices in each vertex's adjacent edge list are arranged continuously in physical address. Improvement on memory locality can reduce the cache miss rate.
- **Reorder graph's bandwidth:** Graphs with lower graph bandwidth have a better locality. When the Bit Compression strategy does not work well with sparse graphs(e.g. roadmap graph), we reorder the initial graph by *Reverse Cuthill-McKee Algorithm* to reduce the graph's bandwidth.
- **Warmup Cache:** Before begin processing workload batches, we execute a batch of randomly generated queries to warm up cache.

7. Third Party Libraries

- **Jemalloc 3.6.0**
- **Intel Threading Building Blocks 4.3**