High-Performance Graph Primitives on the GPU: Design and Implementation of Gunrock

Yangzihao Wang

University of California, Davis

yzhwang@ucdavis.edu

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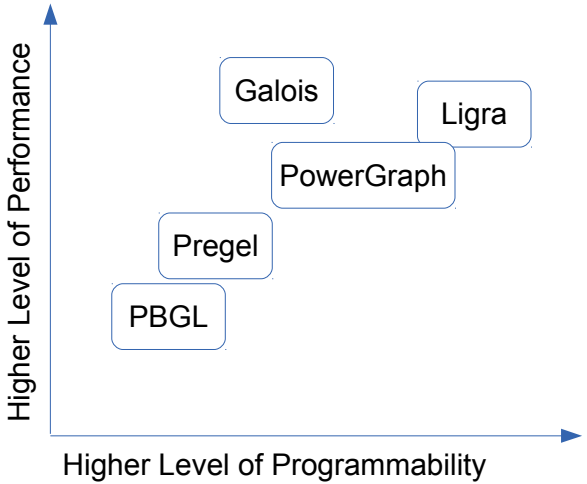
Problem Overview

There is a significant demand for efficient parallel framework for processing and analytics on large-scale graphs.

Applications in fields such as: Social Media, Science and Simulation, Advertising, and Web.

Graph Processing on the CPU



Graph Processing on the GPU

Initial results show that GPU computing is promising for future processing of large-scale graphs. Most current research on GPU graph processing focuses on the challenge of irregular memory accesses and work distribution. However, two gaps in graph computation on the GPU are overlooked.

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- **Algorithmic and Implementation Gap:** few algorithms have efficient single-node GPU implementations when compared to the state of the art on CPUs, and multi-node GPU implementations are even rarer.

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- **Algorithmic and Implementation Gap:** few algorithms have efficient single-node GPU implementations when compared to the state of the art on CPUs, and multi-node GPU implementations are even rarer.
- **Programmability Gap:** the implementations of these algorithms are complex and require expert programmers. The resulting code couples graph computation to parallel graph traversal, and is difficult to maintain and extend.

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- **Programmability:** To be expressive enough to represent a wide variety of graph computations.
- **Performance:** To leverage the highest-performing GPU computing primitives.

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Common Characteristics of Graph Problems

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- **Heterogenous Node Degree Distribution:** Several real-world graphs have such scale-free structure whose degree distribution follows a power law, at least asymptotically, which brings challenge on load-balancing.
- **Iterative Convergent Process:** Start with a working queue contains a subset of the graph, iteratively do the computation, will finally converge.

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- **Idempotent Operation:** Whether to permit a vertex to appear multiple times in frontier(s) from one or more iterations.

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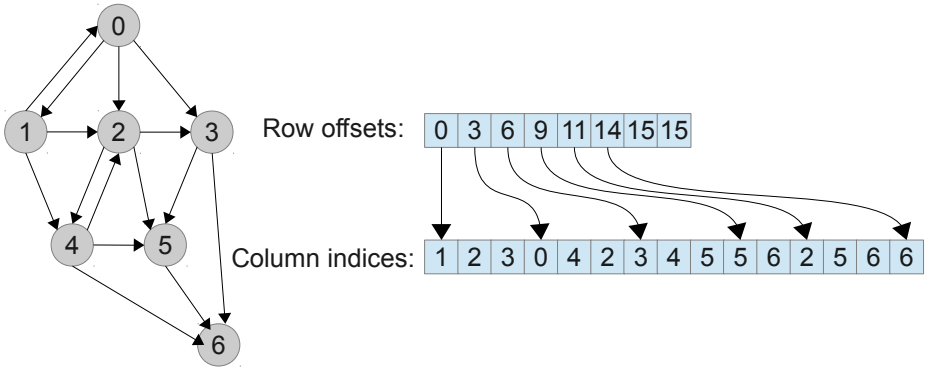
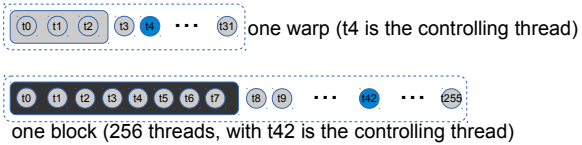
Graph Data Representation

Gunrock uses compressed sparse row (CSR) format for vertex-centric operations and edge list for edge-centric operations.



Workload Mapping Strategies (What makes Gunrock traversal fast?)

- **The Problem:** Write various-length neighbor lists of vertices into an output queue.
- **Per-thread+Per-warp and Per-CTA:** Develop specialized workload mapping strategies according to neighbor list's size.



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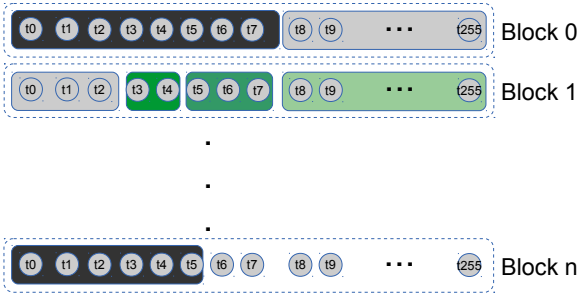
- **Partitioned Load-balancing:** Organize groups of edges into equal-length chunks and assigning each chunk to a block.



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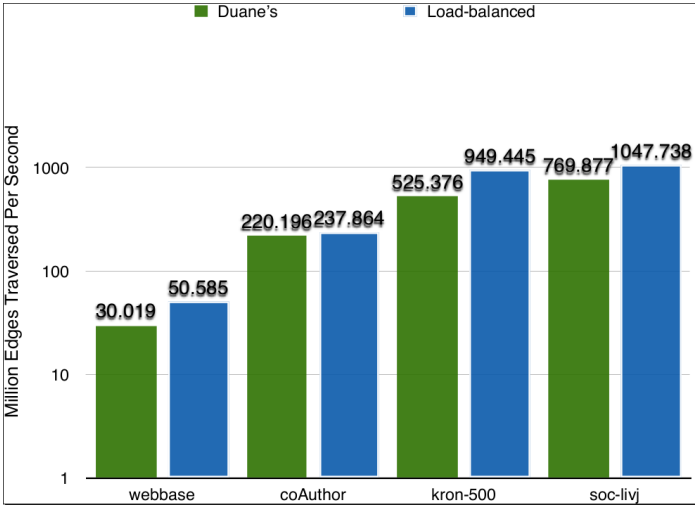

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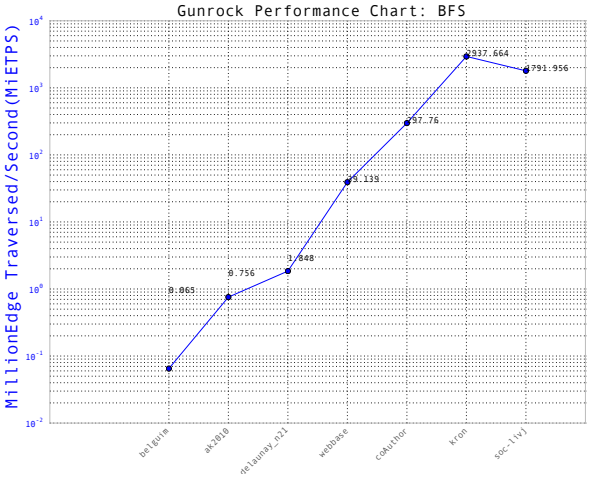
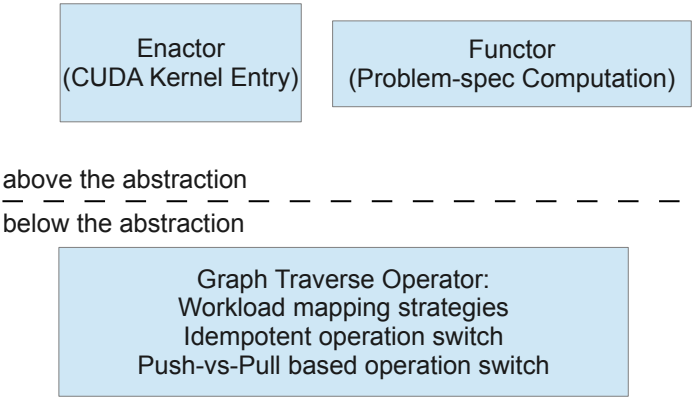


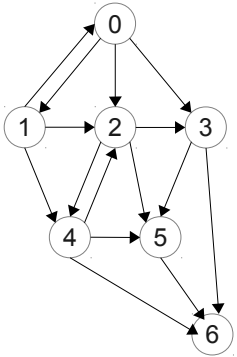
A High-Level View of Programming Model

Bulk iterative processes which iterate between graph traversal and computation using operators and functors.



Graph Primitive Example: BFS

A breadth-first search (BFS) algorithm takes a graph and a source vertex s, and computes a breadth-first search tree rooted at s containing all vertices reachable from s. Our implementation will compute the predecessor and the distance from source vertex for each vertex.



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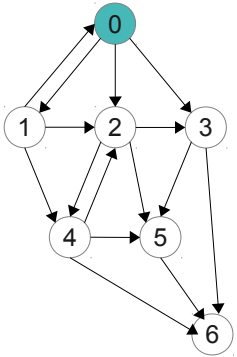

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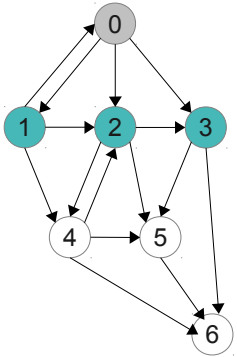

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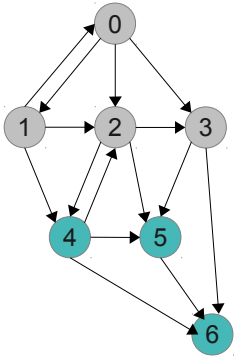

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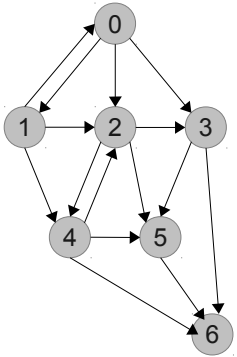

Performance: Speedup

Primitive	webbase1M	coAuthor	socLiveJournal	Kron_g500
BFS	NA(GPU:0.001s)	4	27	22
CC	3	10	13	NA(GPU:0.253s)
BC	2	5	10	10
SSSP	2	15	10	16
PR	13	NA(GPU:0.1s)	NA(GPU:3.4s)	NA(GPU:29.6s)

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What's Next?

- More flexible operator set;
- More graph types and data structures;
- External memory and multi-node GPUs support;
- Non-regular Graph Operations/Advanced graph primitives.

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Thank you!

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