Theory and Implementation of Dynamic Data Structures for the GPU

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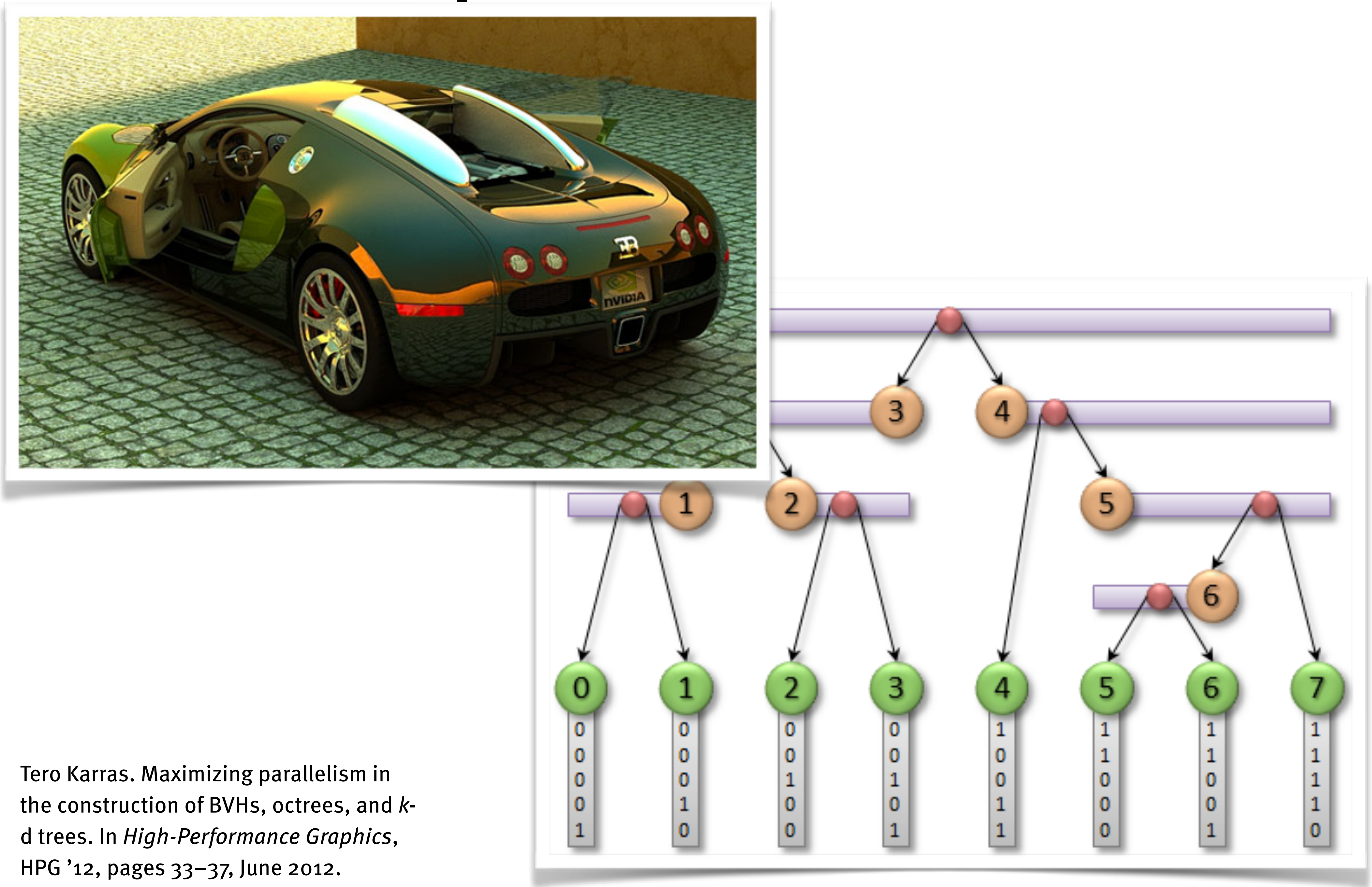


Tero Karras. Maximizing parallelism in the construction of BVHs, octrees, and *k*-d trees. In *High-Performance Graphics*, HPG '12, pages 33–37, June 2012.

The problem

- Many data structures are built on the CPU and used on the GPU
- Very few data structures can be *built* on the GPU
  - Sorted array
  - (Cuckoo) hash table
  - Several application-specific data structures (e.g., BVH tree)
- No data structures can be *updated* on the GPU

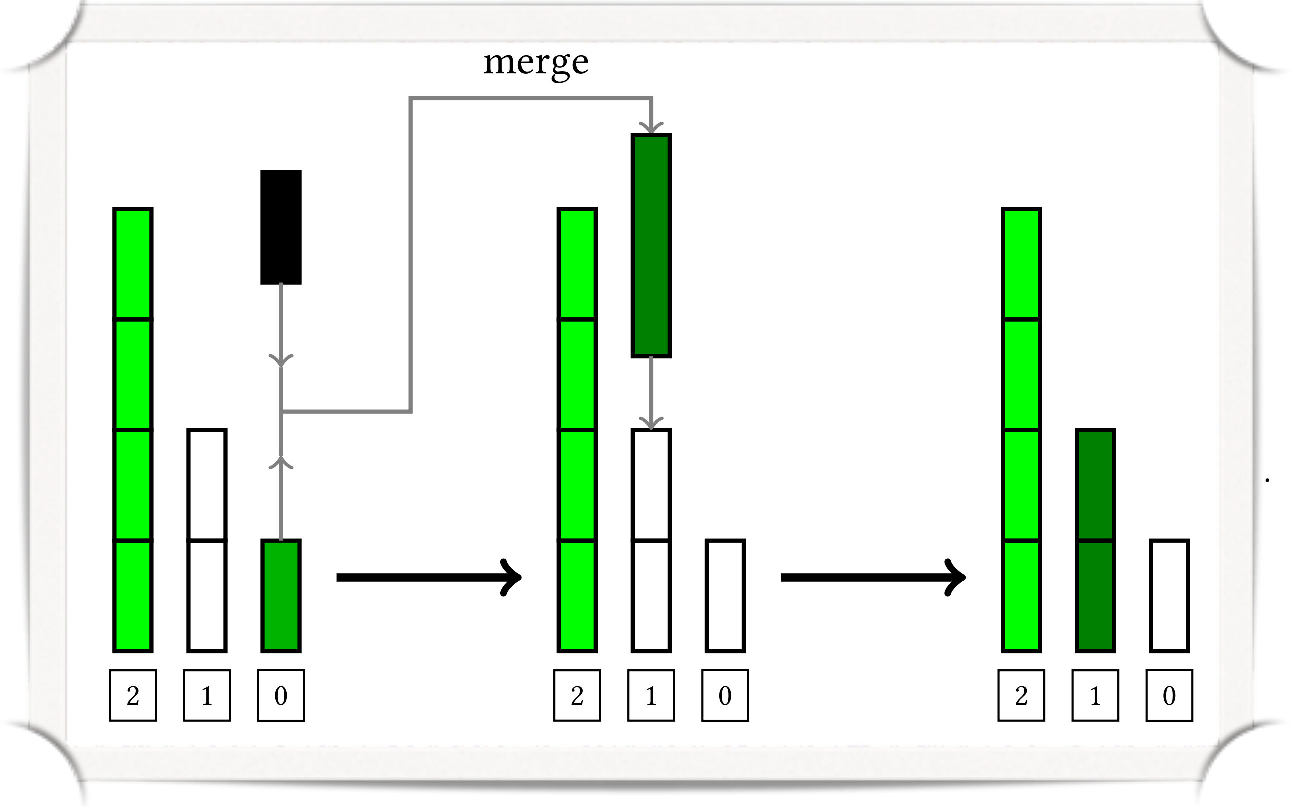
Scale of updates

- Update 1–few items
  - Fall back to serial case, slow, probably don’t care
- Update very large number of items
  - Rebuild whole data structure from scratch
- Middle ground: our goal
  - Questions: How and when?

Approach

- Pick data structures useful in serial case, try to find parallelizations?
- Pick what look like parallel-friendly data structures with parallel-friendly updates?

Log-structured merge tree



Michael A. Bender, Martin Farach-Colton, Jeremy T. Fineman, Yonatan R. Fogel, Bradley C. Kuszmaul, and Jelani Nelson. 2007. *Cache-oblivious Streaming B-trees*. In Proceedings of the Nineteenth Annual ACM Symposium on Parallel Algorithms and Architectures (SPAA '07). 81–92.

- Supports dictionary and range queries
- log *n* sorted levels, each level 2x the size of the last
- Insert into a filled level results in a merge, possibly cascaded. Operations are *coarse* (threads cooperate).

LSM results/questions

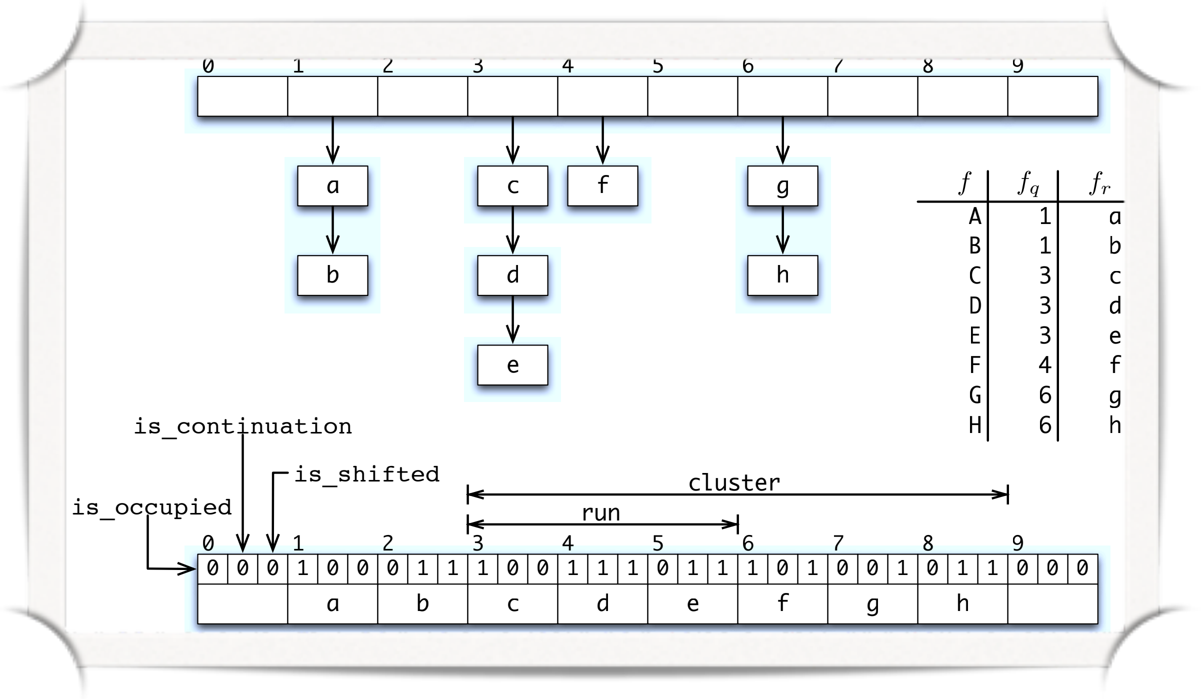
- Update rate of 225M elements/s
  - 13.5x faster than merging with a sorted array
- Lookups: 7.5x/1.75x slower than hash table/sorted array
- Deletes using tombstones
- *Semantics for parallel insert/delete operations?*
- *Minimum batch size?*
- *Atom size for searching?*
- *Fractional cascading?*

Saman Ashkiani, Shengren Li, Martin Farach-Colton, Nina Amenta, and John D. Owens. *GPU COLA: A dynamic dictionary data structure for the GPU*. January 2017. Unpublished.

Quotient Filter

- Probabilistic membership queries & lookups: false positives are possible

- Comparable to a Bloom filter but also supports deletes and merges



f	f_q	f_r
A	1	a
B	1	b
C	3	c
D	3	d
E	3	e
F	4	f
G	6	g
H	6	h

0	1	2	3	4	5	6	7	8	9
0 0 0	1 0 0	0 1 1	1 0 0	1 1 1	0 1 1	1 0 1	0 0 1	0 1 1	0 0 0
	a	b	c	d	e	f	g	h	

. Michael A. Bender, Martin Farach-Colton, Rob Johnson, Russell Kraner, Bradley C. Kuszmaul, Dzejla Medjedovic, Pablo Montes, Pradeep Shetty, Richard P. Spillane, and Erez Zadok. 2012. *Don't Thrash: How to Cache Your Hash on Flash*. Proceedings of the VLDB Endowment 5, 11 (Aug. 2012), 1627–1637.

QF results/questions

- Lookup perf. for point queries: 3.8–4.9x vs. BloomGPU
- Bulk build perf.: 2.4–2.7x vs. BloomGPU
- Insertion is significantly faster for BloomGPU
- Similar memory footprint
- 3 novel implementations of bulk build + 1 of insert
- *Bulk build == non-associative scan*
- *Limited to byte granularity*

Afton Geil, Martin Farach-Colton, and John D. Owens. GPU Quotient Filters: *Approximate Membership Queries on the GPU*. January 2017. Unpublished.

Cross-cutting issues

- Useful models for GPU memory hierarchy
- Independent threads vs. cooperative threads?
  - More broadly, what’s the right work granularity?
- Memory allocation (& impact on hardware)
- Cleanup operations, and programming model implications
- Integration into higher-level programming environments
  - Use cases! Chicken & egg problem