Parallel Combining: Benefits of Explicit Synchronization

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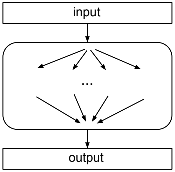
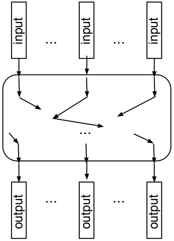
Parallel Programs and Concurrent Data Structures

Parallel programs



Concurrent data structures



Batched Data Structures

- Given a "batch" and a state produces a new state and a vector of responses.
- Parallel batched data structures
  - Static multithreading: PRAM, Bulk synchronous [Val90], asynchronous PRAM [Gib89], ...
  - Dynamic multi-threading: spawn, sync, parallel-for, work-stealing
- Can we use the benefits of parallel batched data structures?

Combining [Oyama et al., 1999], [Hendler et al., 2010]

- Put request into publication list;
- Then, compete for a lock: if won — becomes a combiner, otherwise, becomes a client;
- The combiner applies requests sequentially.

- Hierarchical Flat-Combining [Hendler et al., 2010]
  - Two levels of combining.

Parallel Combining

- Put request into publication list;
- Then, compete for a lock: if won — becomes a combiner, otherwise, becomes a client;
- The combiner and clients apply requests in parallel using a parallel batched data structure.

Parallel Combining

```
execute(method, input):
  req ← new Request()
  request.method ← method
  request.input ← input
  req.status ← INITIAL
  if ℂ.addRequest(req):
    A ← ℂ.getRequests()
    COMBINER_CODE
    ℂ.release()
  else:
    while req.status = INITIAL:
      nop
    CLIENT_CODE
  return
```

Read-Optimized Data Structures

- Operations of two types:
  - Read-only may proceed in parallel;
  - Updates not always
- Combiner collects requests.
  - Read-only are performed in parallel on clients;
  - Updates are performed sequentially by the combiner.

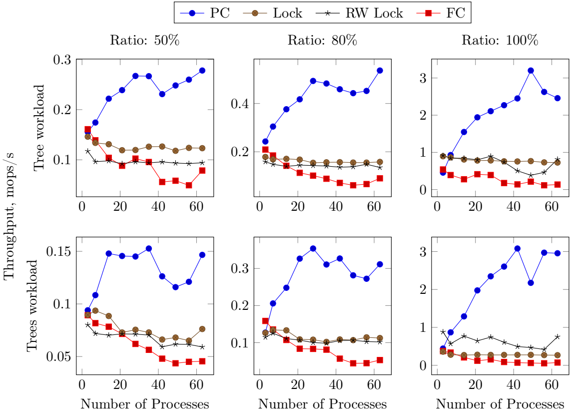
Read-Optimized Data Structures

- The resulting concurrent data structures are linearizable.

Read-Optimized Data Structures. Example

- Dynamic graph [Holm et al., 2001]:
  - Read-only: `areConnected(u, v)`
  - Update: `addEdge(u, v)`, `removeEdge(u, v)`

Dynamic graph. Experiments



Priority queue

- Ordered set of values;
- `Insert(v)`;
- `ExtractMin()`.

- Challenge: find a parallel batched algorithm with complexity that depends only on the batch size and the size of the heap.

Binary heap

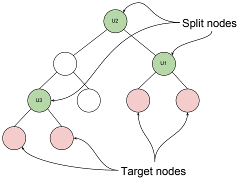
- Binary heap stored in array `a[1,..., s]`: node i has children $2i$ and $2i+1$ with higher values.
- Algorithm [Gonnet and Munro, 1986]
  - `ExtractMin()`: swap `a[1]` and `a[s]`, then sift-down;
  - `Insert(v)`: traverse the path from the root to `a[s + 1]`.

Parallel Batched Binary Heap. ExtractMin

- Combiner with E `extractMin` requests:
  - Locate E nodes with the smallest values using Dijkstra-like algorithm;
  - Swap the values with E latest values `a[s - E + 1]`, ..., `a[s]`;
  - Initiate parallel sift-down on clients from the located nodes;
  - Done using hand-over-hand locking.

Parallel Batched Binary Heap. Insert

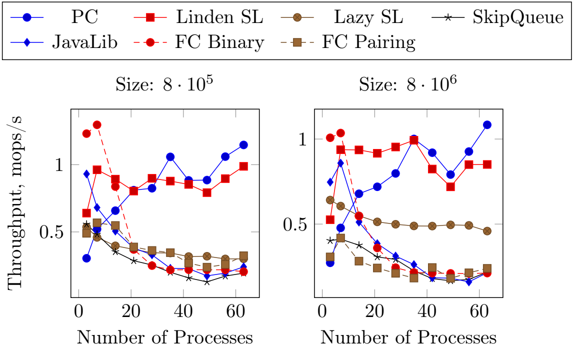
- Combiner with I `insert` requests:
  - Target nodes: `a[s + 1], ...,` `a[s + |I|]`;
  - Locate `|I| - 1` split nodes;
  - Sort $v_{s+1}, \ldots, v_{s+|I|}$ values to insert;
  - Initiate a traversal from the root to target nodes, splitting set of values to insert into two sets in split nodes.



Parallel Batched Binary Heap

- The resulting concurrent binary heap is linearizable.
- Combiner and clients perform $O(c + \log s)$ RMRs in CC and DSM models each and $O(c \cdot (\log c + \log s))$ RMRs in CC and DSM models in total.

Priority Queue. Experiments



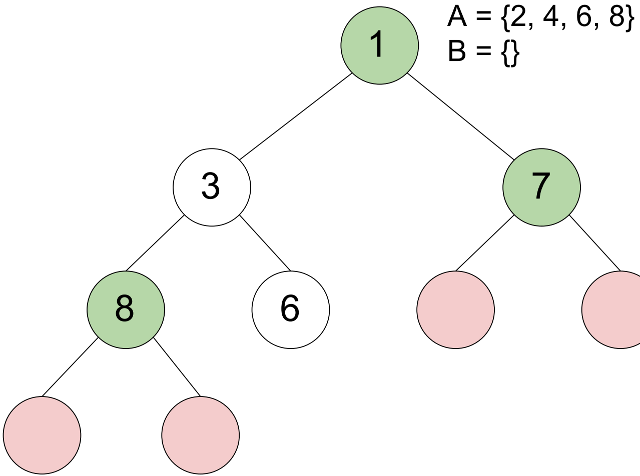
Conclusion

- It is possible to build efficient concurrent data structures from their parallel batched counterpart.
- We affirm it by considering two data structures: dynamic graph and priority queue.
- Which other data structures that can benefit from parallel combining?
    - For example, dynamic tree.

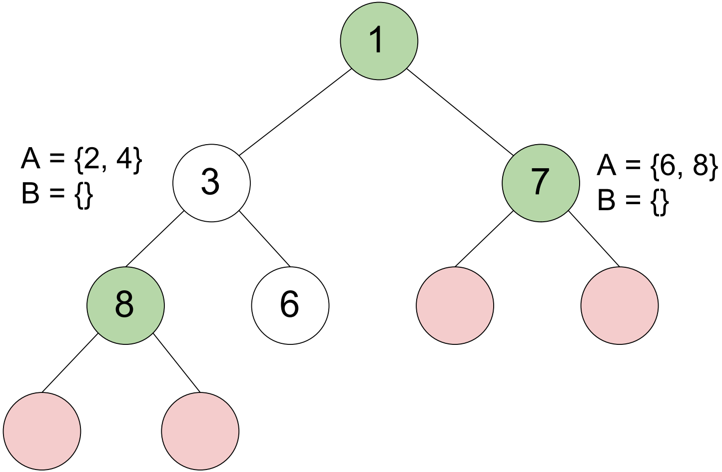
Thank you for your attention

Questions?

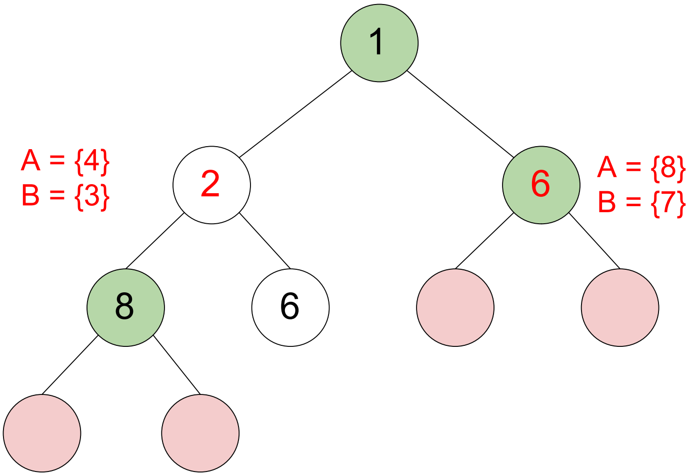
Parallel Batched Binary Heap. Insert



Parallel Batched Binary Heap. Insert



Parallel Batched Binary Heap. Insert



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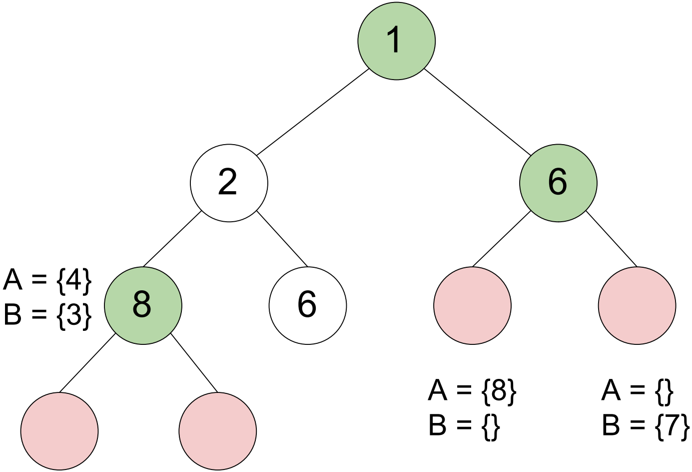
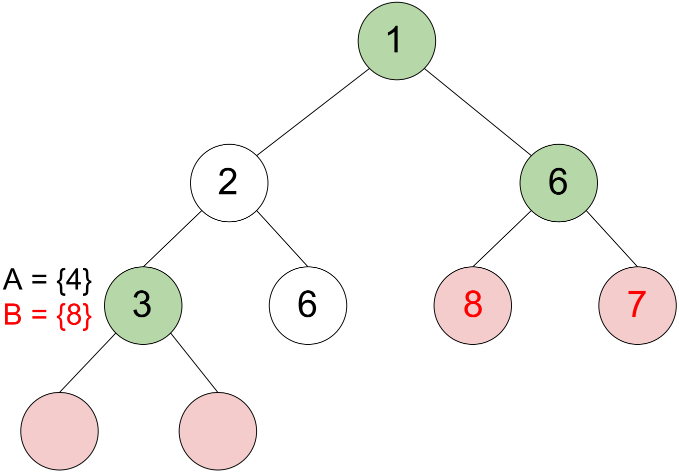
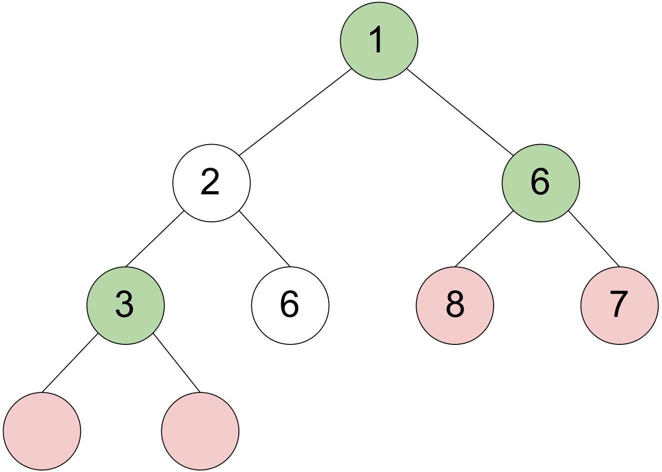


Parallel Batched Binary Heap. Insert



Parallel Batched Binary Heap. Insert



A = {4}
B = {}

A = {}
B = {8}

Parallel Batched Binary Heap. Insert