Low-Latency Graph Streaming Using Compressed Purely-Functional Trees

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Streaming Graph Processing

...

...
insert(e_4)

delete(e_3)

insert(e_2)

insert(e_1)

Update Stream

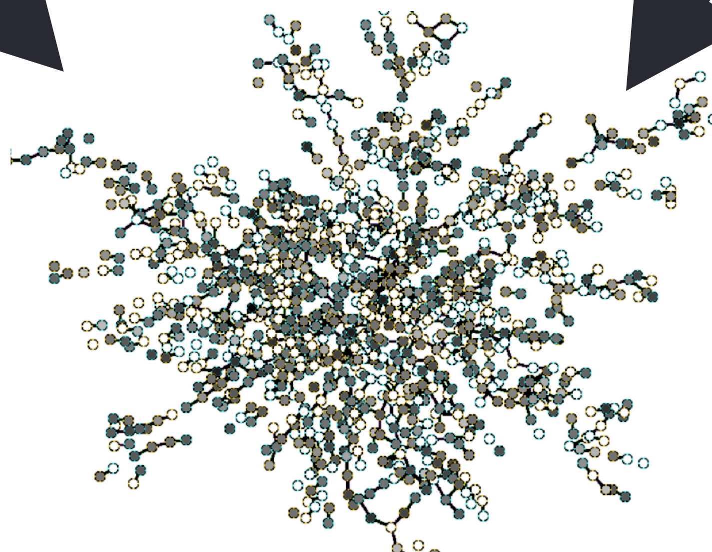
...

ClusteringCoefficient(v)

Connectivity(G)

Reachable(u—>v)?

Query Stream

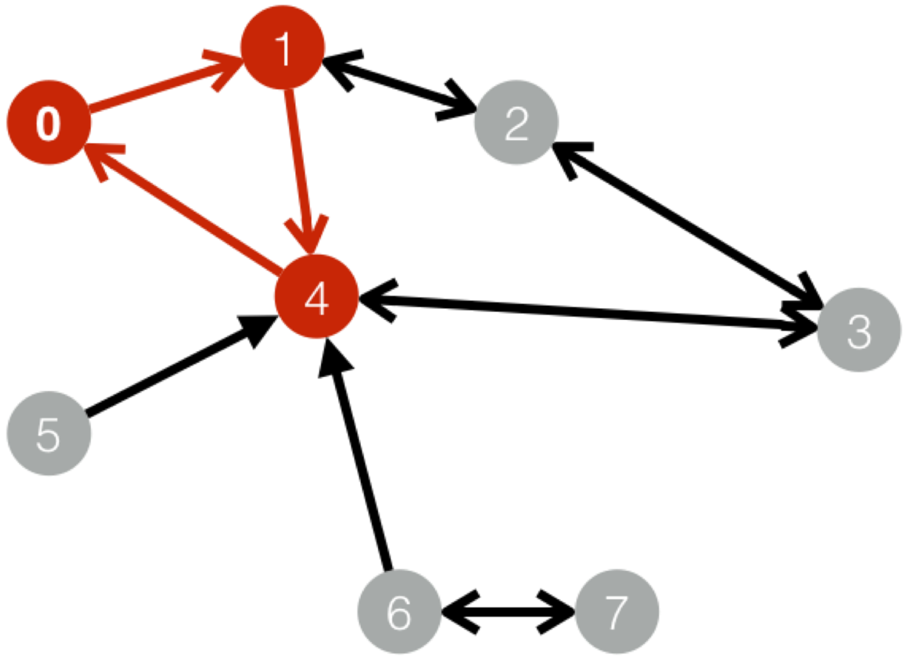


G : graph

Goals: Serializability for updates/queries, achieve low latency and high throughput

Example: Fraud Detection

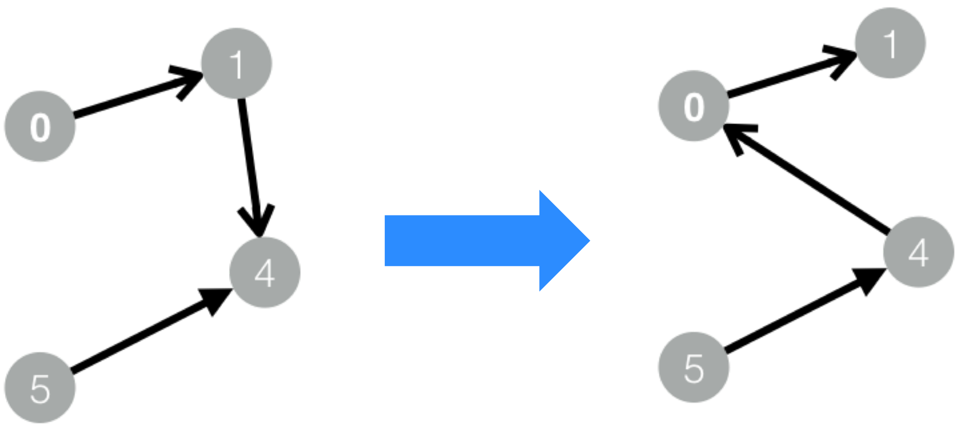
- Bank maintains a transaction graph
- Transactions occur at a high rate (1k-10k/sec)



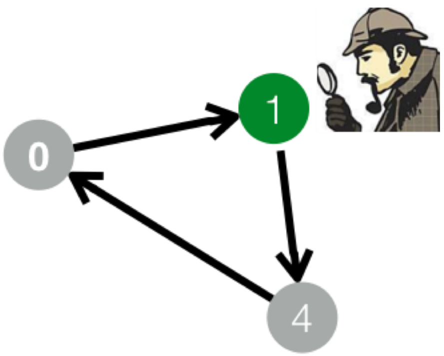
- Goal: quickly detect anomalies in evolving transaction graph

Relaxing Serializability

- Could detect a cycle that never existed!



Evolving graph



Observed graph

Existing Work

- Single Version Systems
  - Maintain a **single** version of the graph
  - Common approach in graph streaming (e.g., STINGER, cuSTINGER, and KickStarter)
  - Need to separate queries from updates for serializability

- Multi-Version Systems
  - Support multiple graph snapshots (e.g., LLAMA, Kineograph, GraphOne, and some graph databases)
  - Snapshots are not space-efficient and lead to high latency

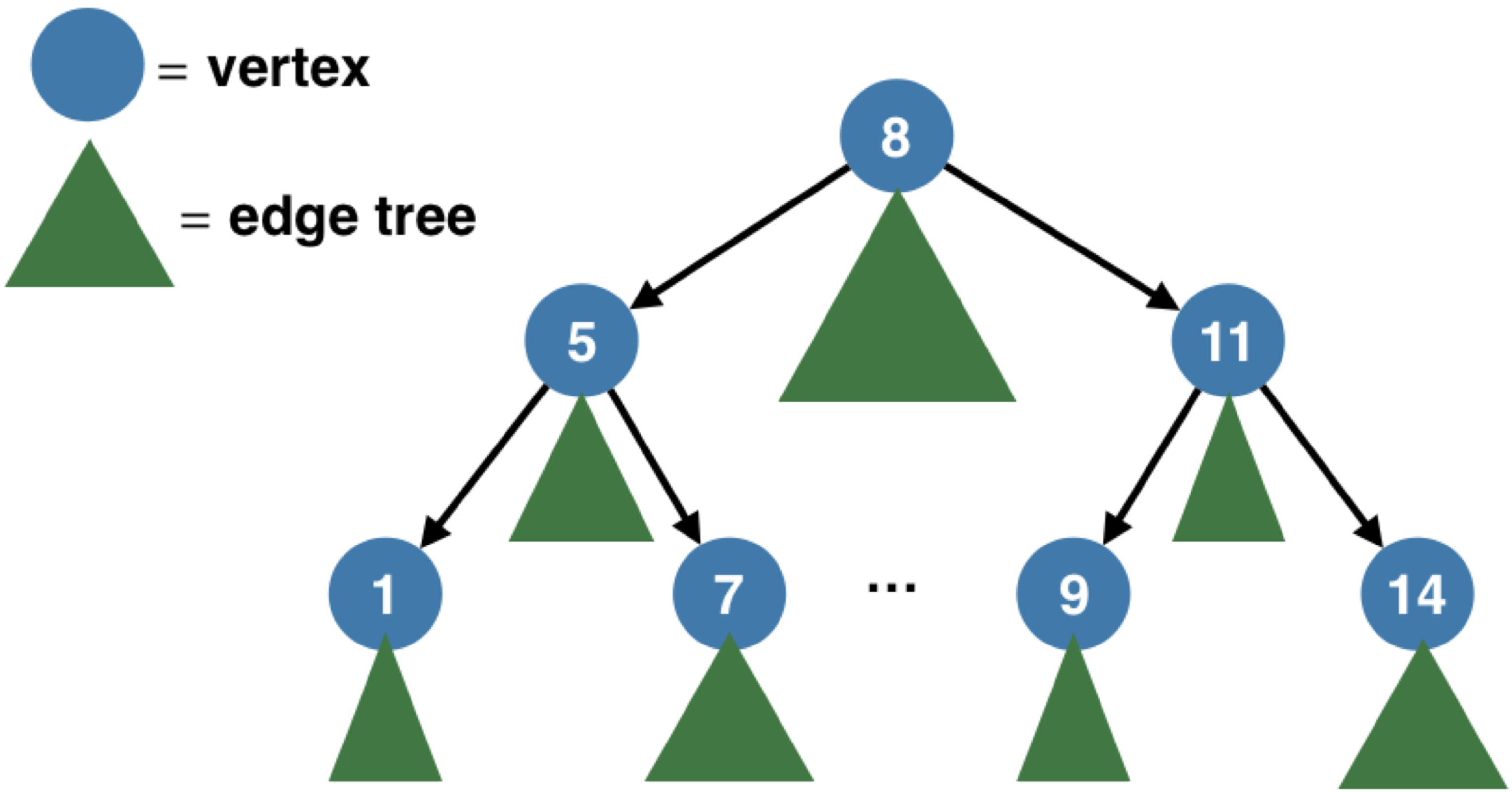
- Our framework **Aspen** uses lightweight snapshots to enable low-latency concurrent queries and updates

Terminology: Streaming vs. Dynamic

- **Streaming graph processing**: Goal is to run algorithms on a graph that is changing in real-time while obtaining serializable results
  - Need to process updates concurrently with algorithm execution
- **Dynamic graph algorithms**: Goal is to update the result of an algorithm based on updates to the graph itself
  - Should be more efficient than recomputing answer from scratch
  - Allows for barriers between algorithm execution and processing updates
- This talk is about streaming graph processing

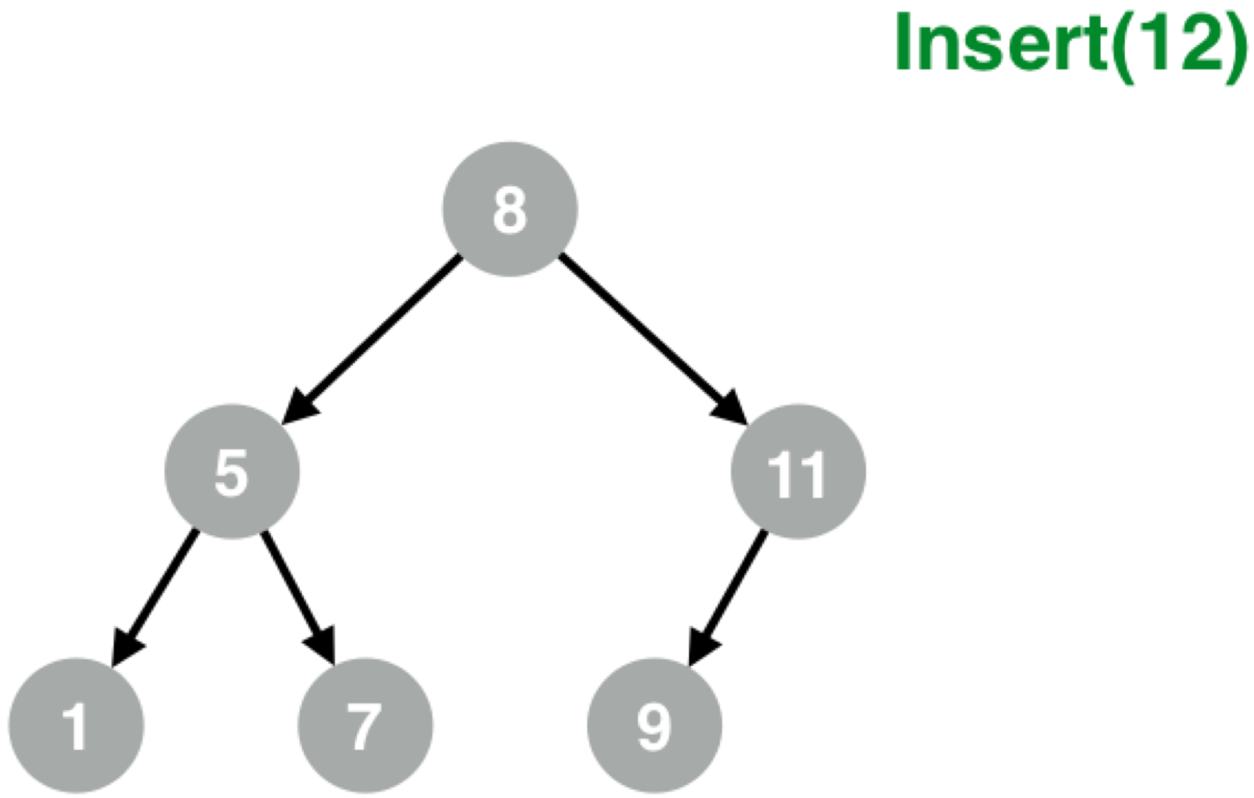
Graphs Using Purely Functional Trees

- Purely functional trees can be updated efficiently (in logarithmic time/space) while retaining old copy of tree
- Aspen uses tree of **vertices**, where each vertex stores a tree of its incident **edges**



Updates via Path Copying

- Easy to generate new versions via path copying



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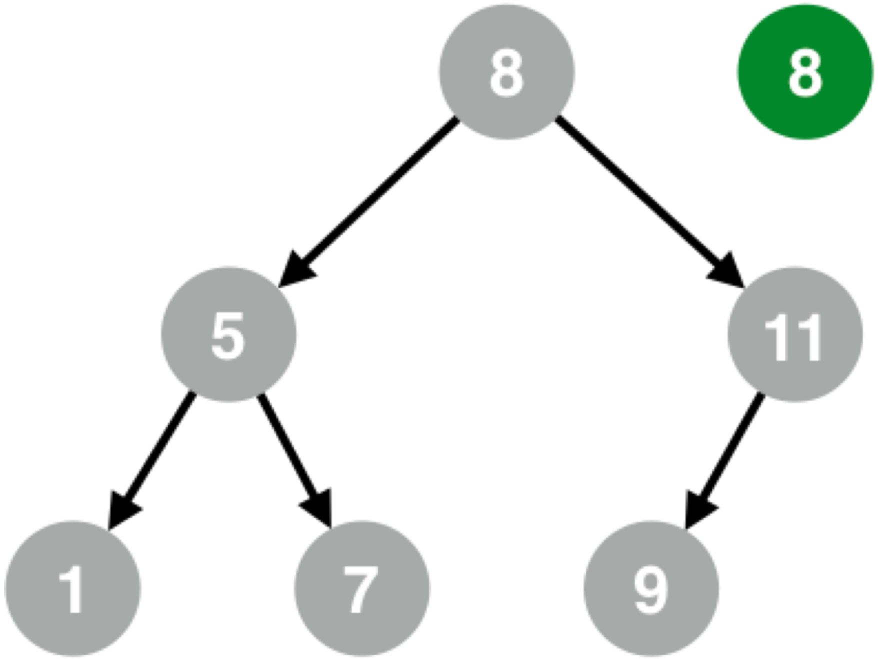
Insert(12)



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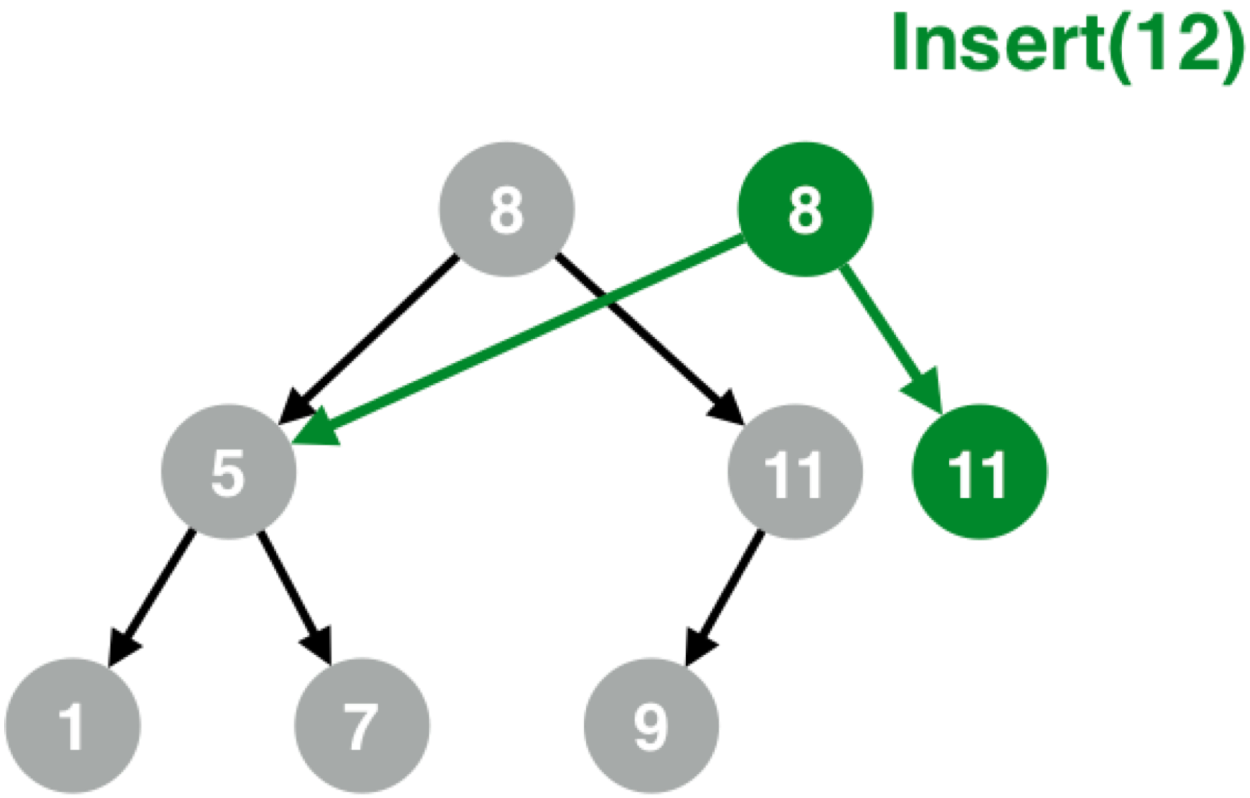

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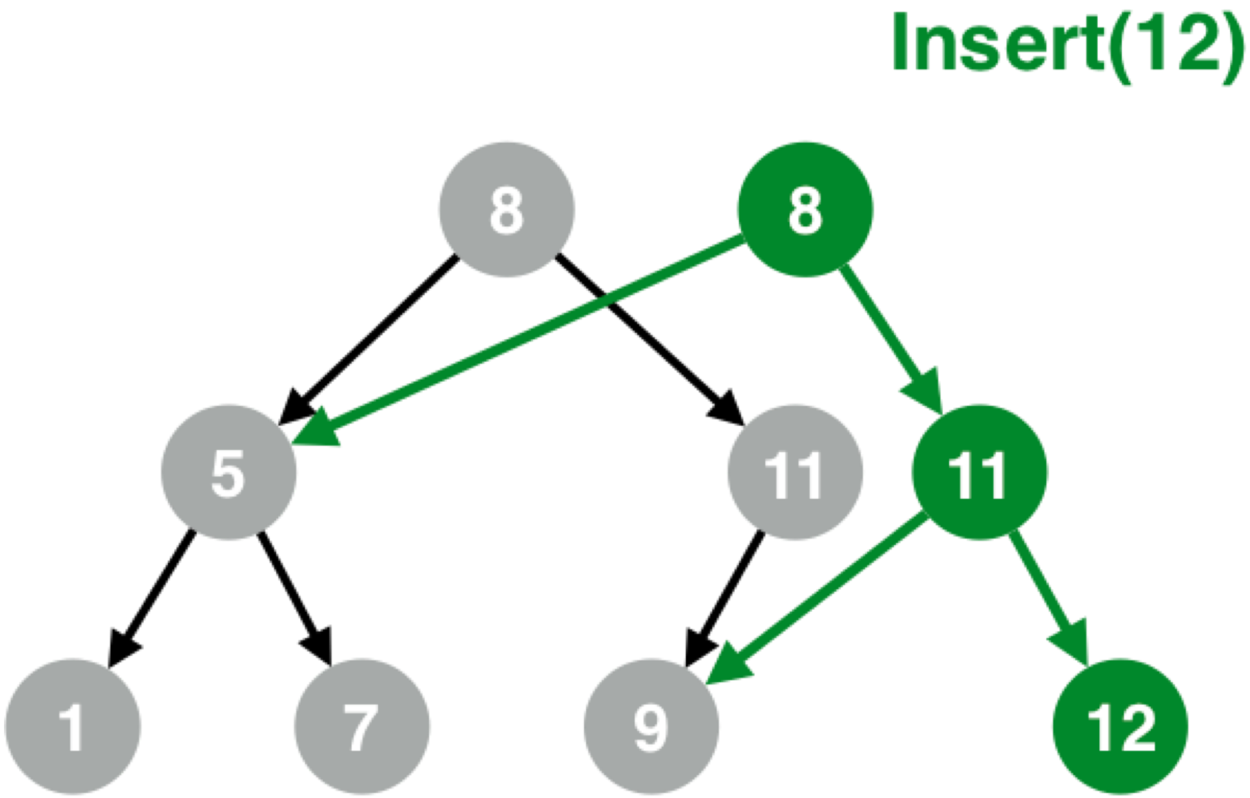
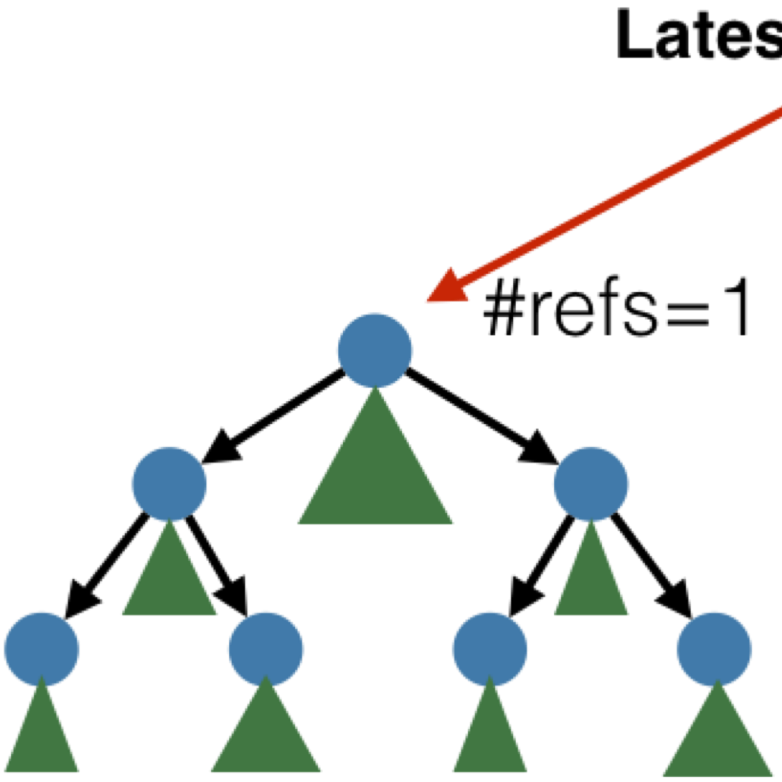


- We can obtain immutability versions of the tree

Immutability Enables Concurrency



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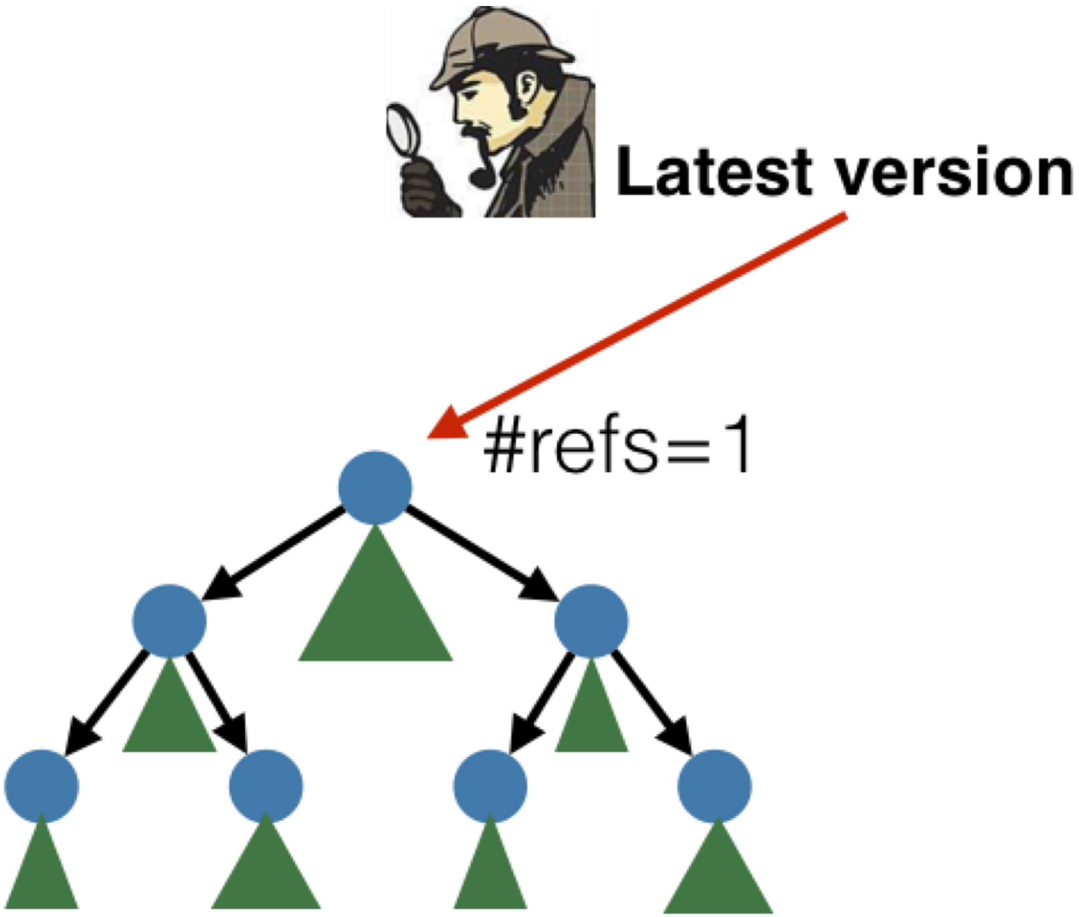

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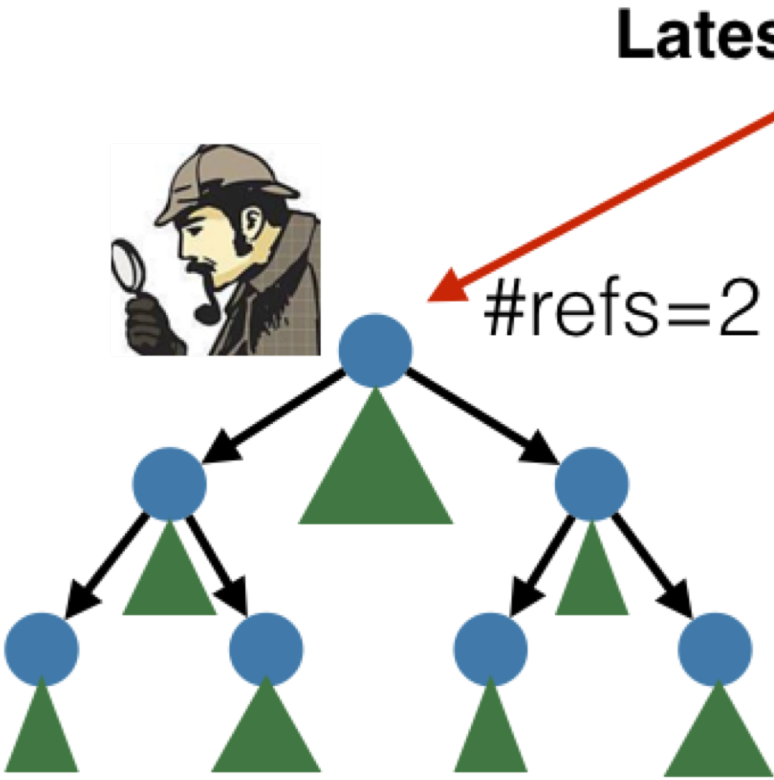

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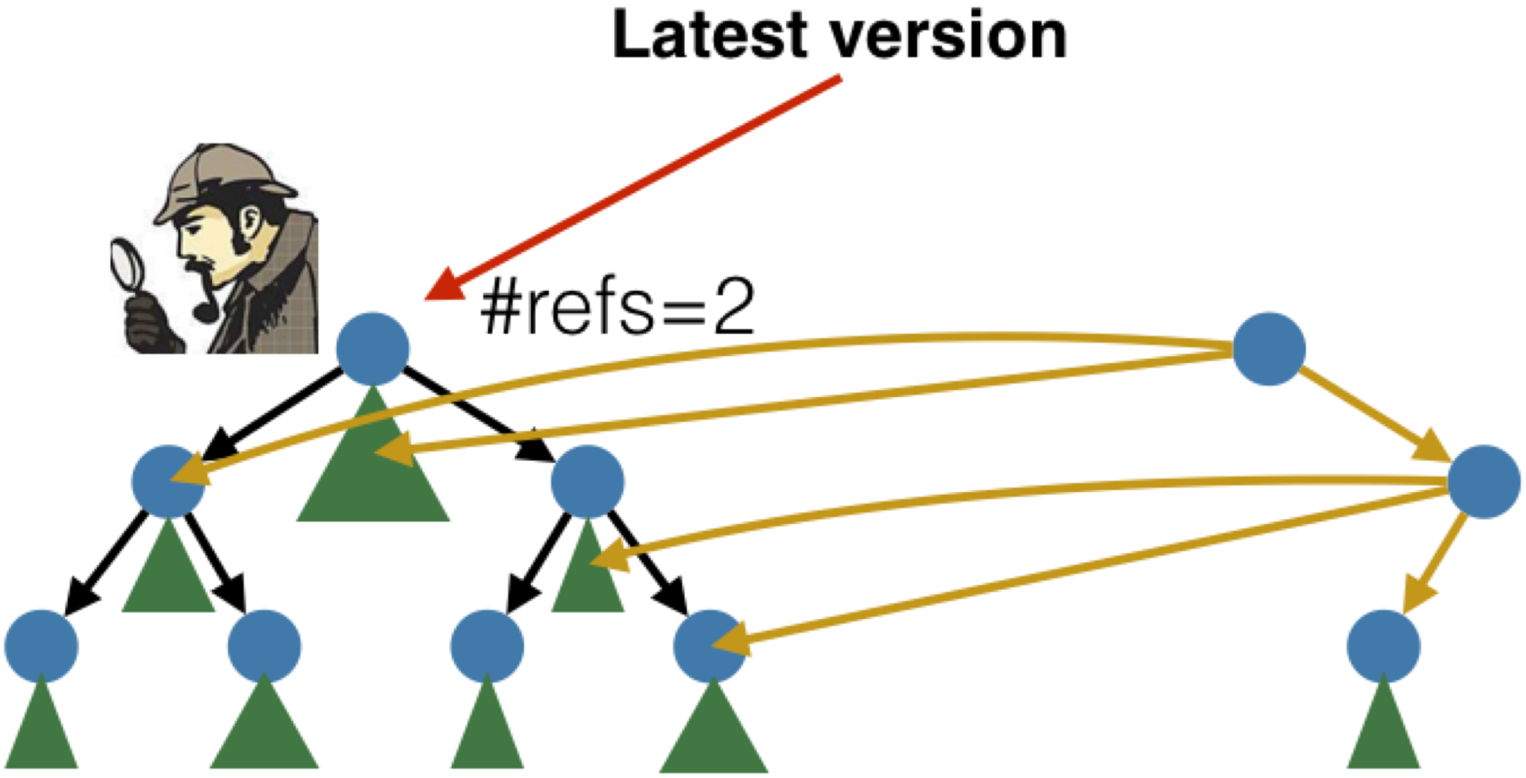

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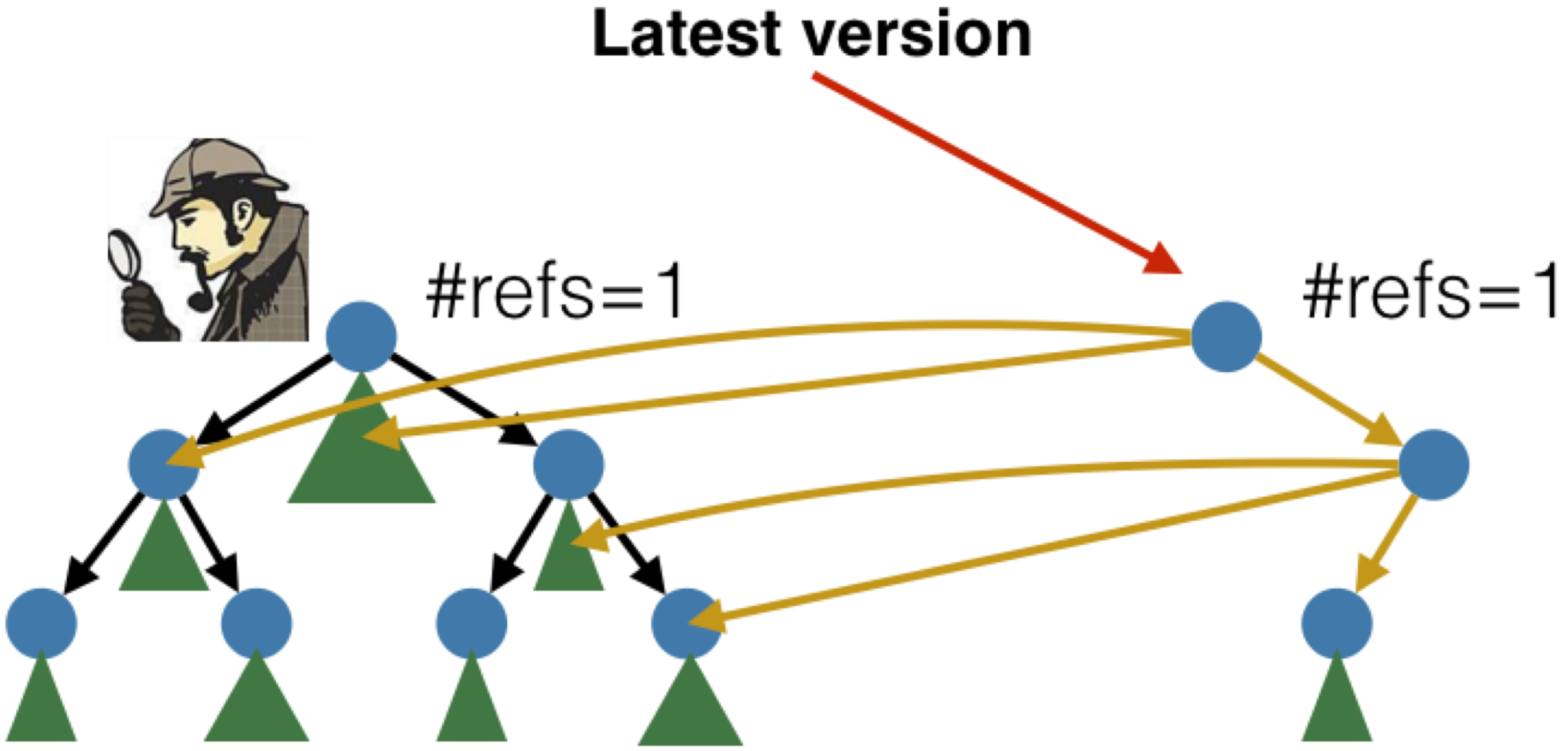

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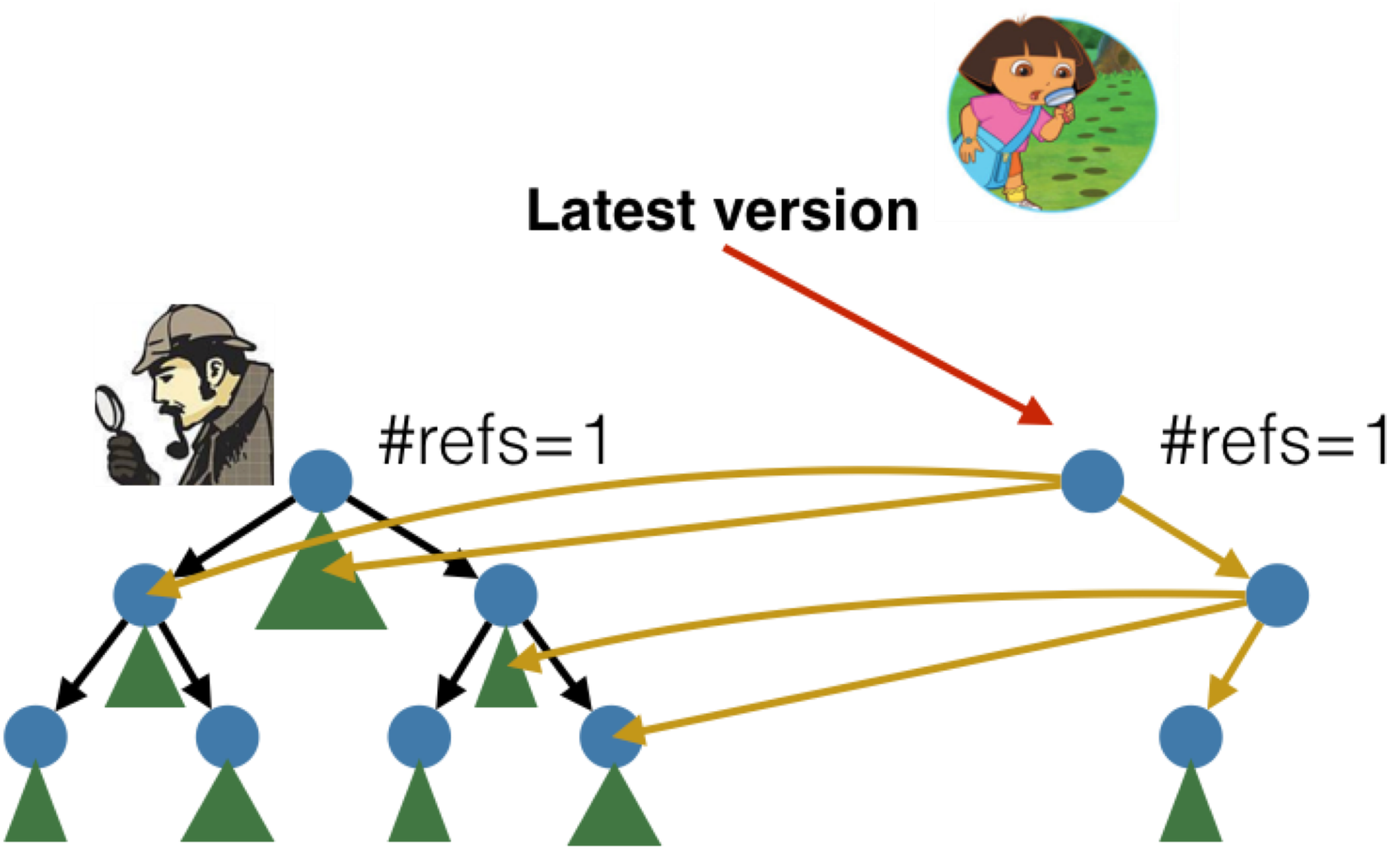

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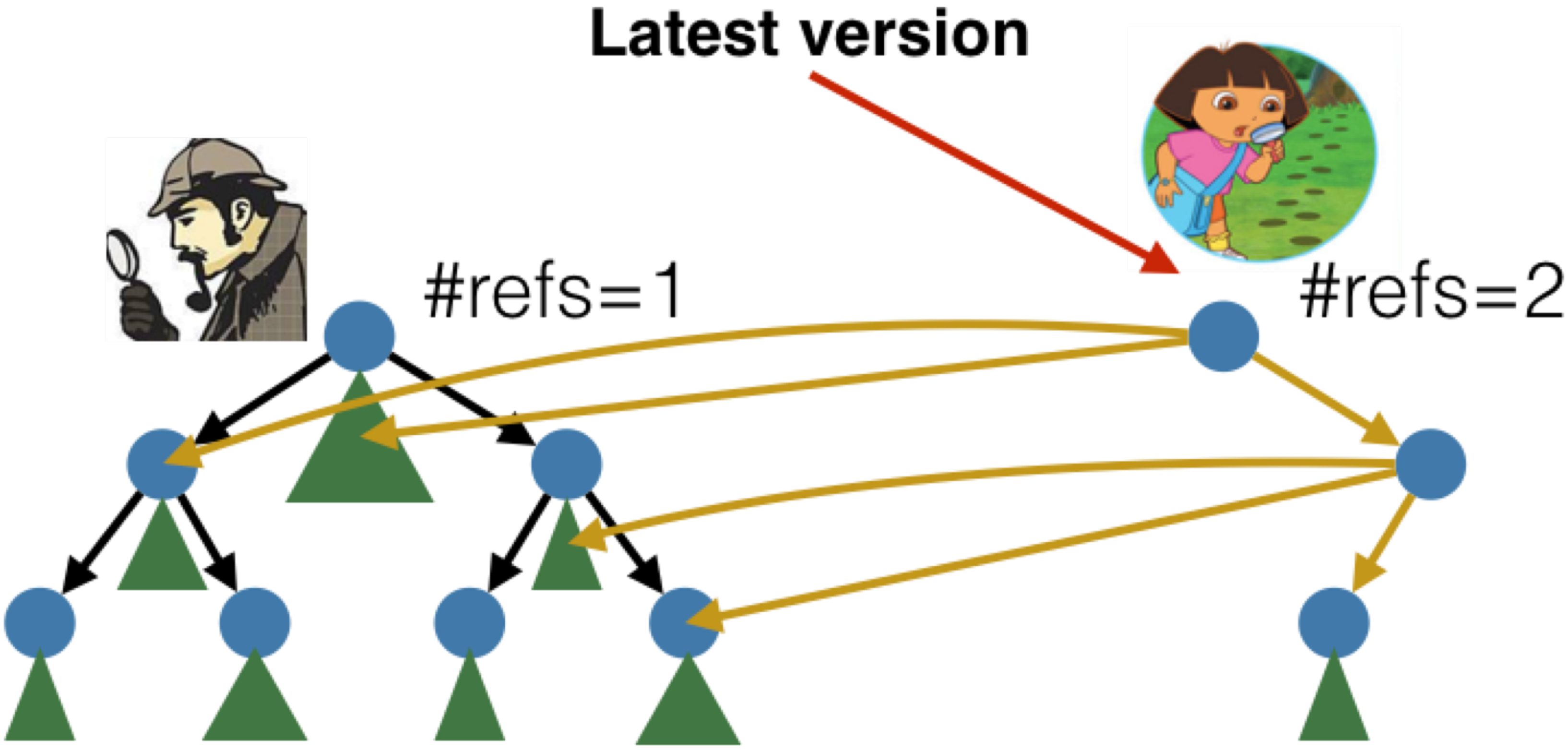
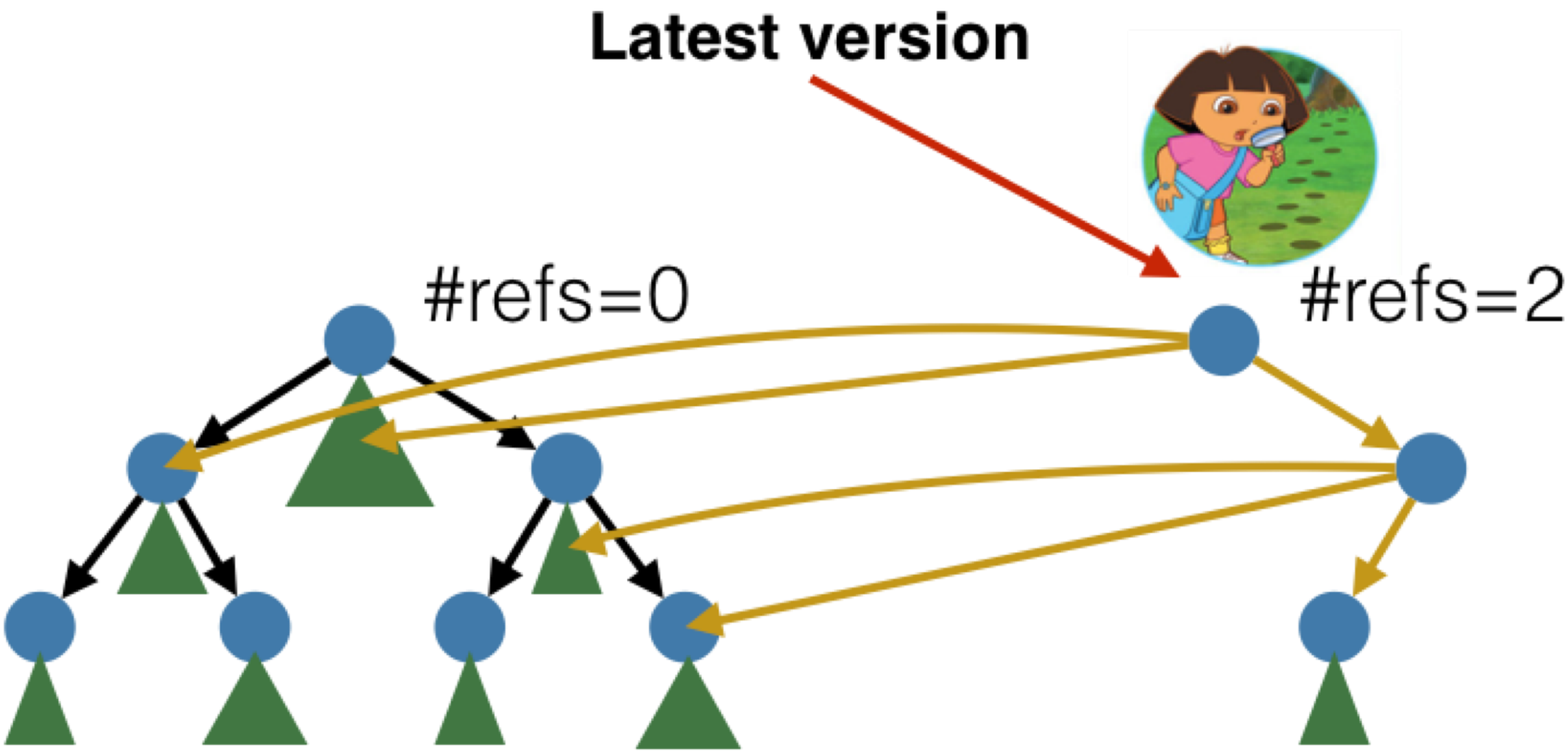


Immutability Enables Concurrency

Garbage collect all tree nodes whose reference count is decremented to 0



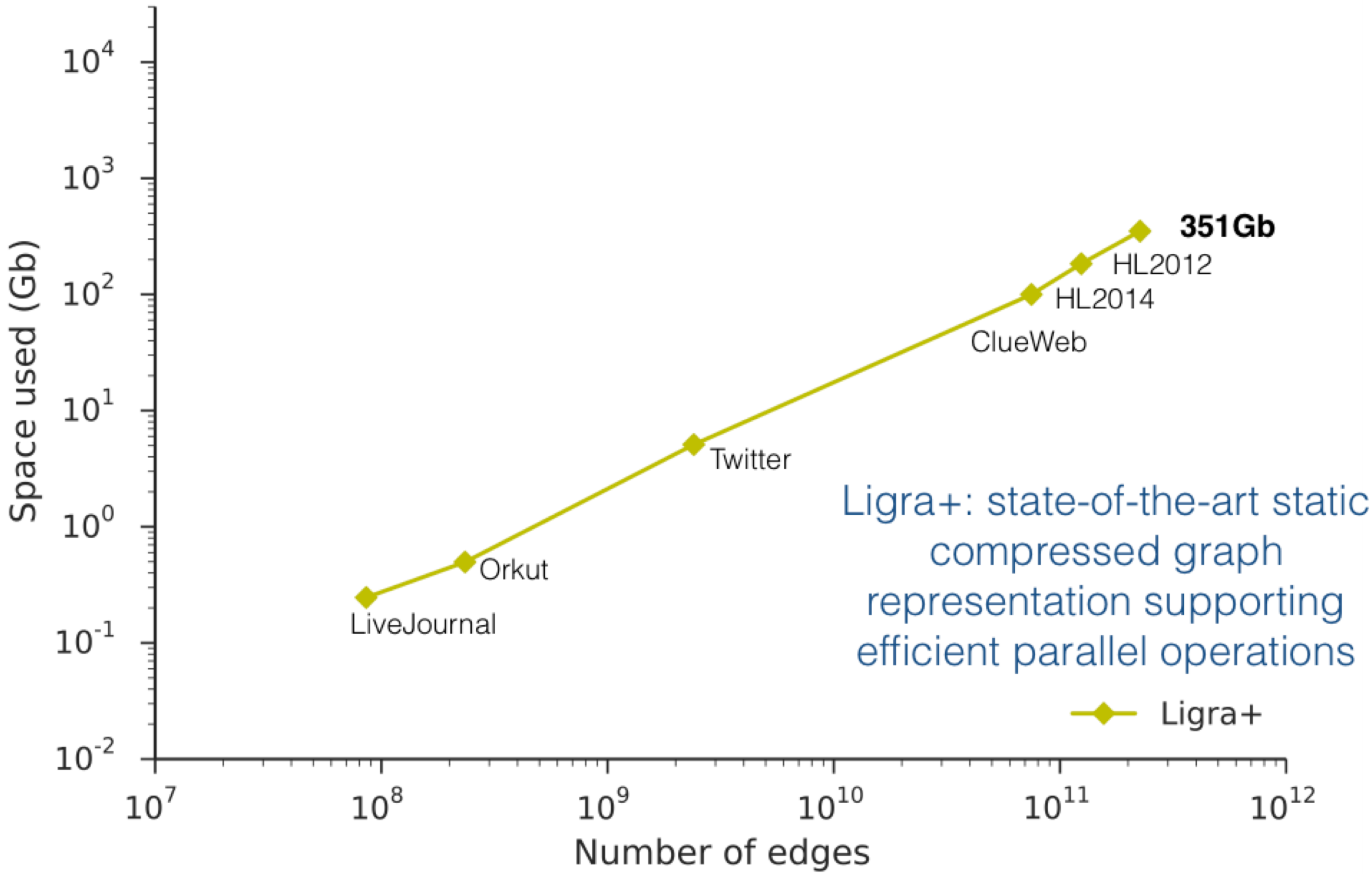
Disadvantages of representing graphs using trees

- Poor Cache Usage
  - One tree node per vertex and edge
  - One cache miss per edge access in the worst case

- Space Inefficiency
  - Need to store children pointers and metadata on tree nodes
  - Lose ability to perform integer compression

Requires close to 7TB of memory to store the symmetrized Hyperlink 2012 graph (225B edges)!

Space Overhead of Graphs using Trees



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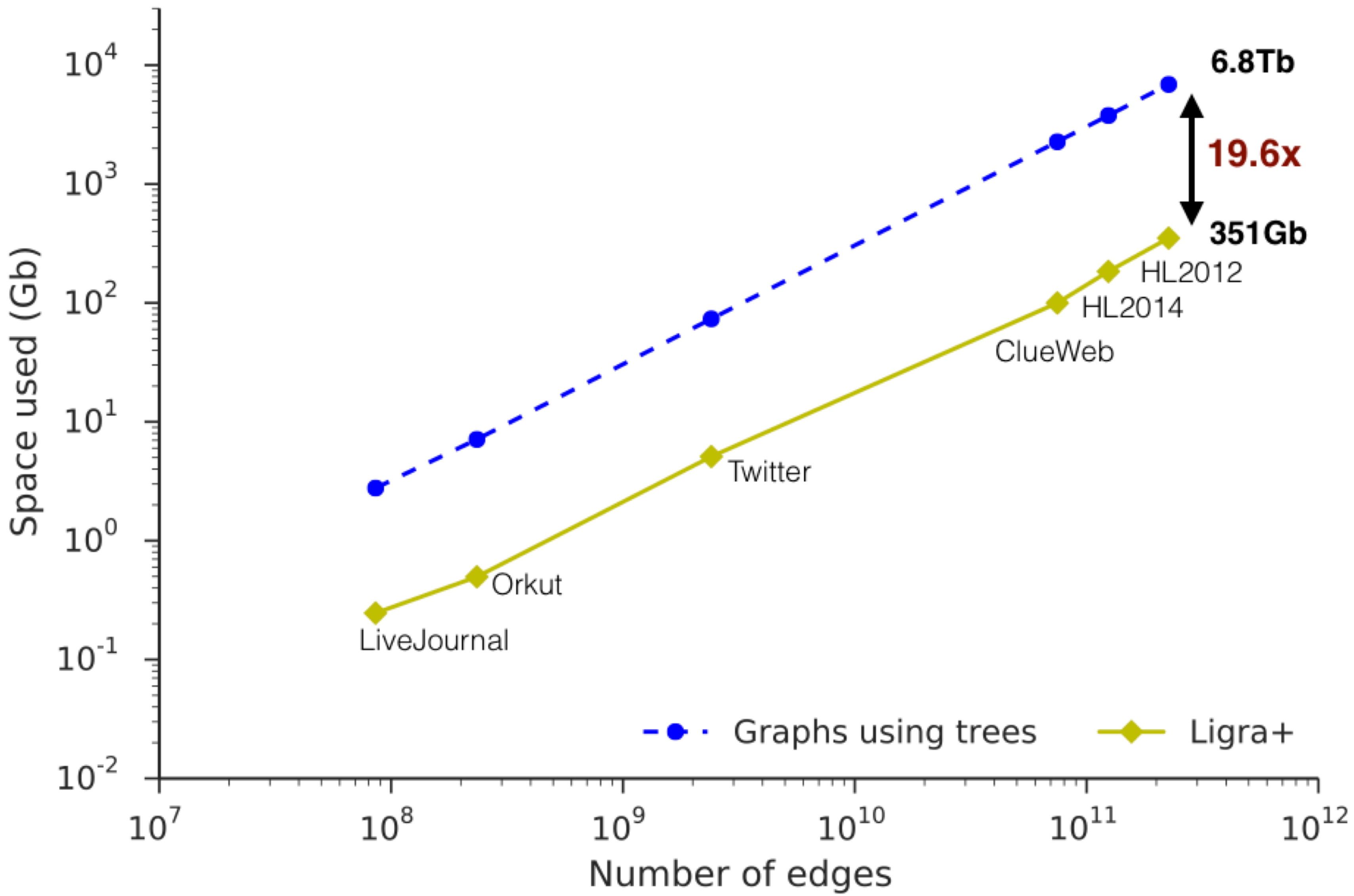
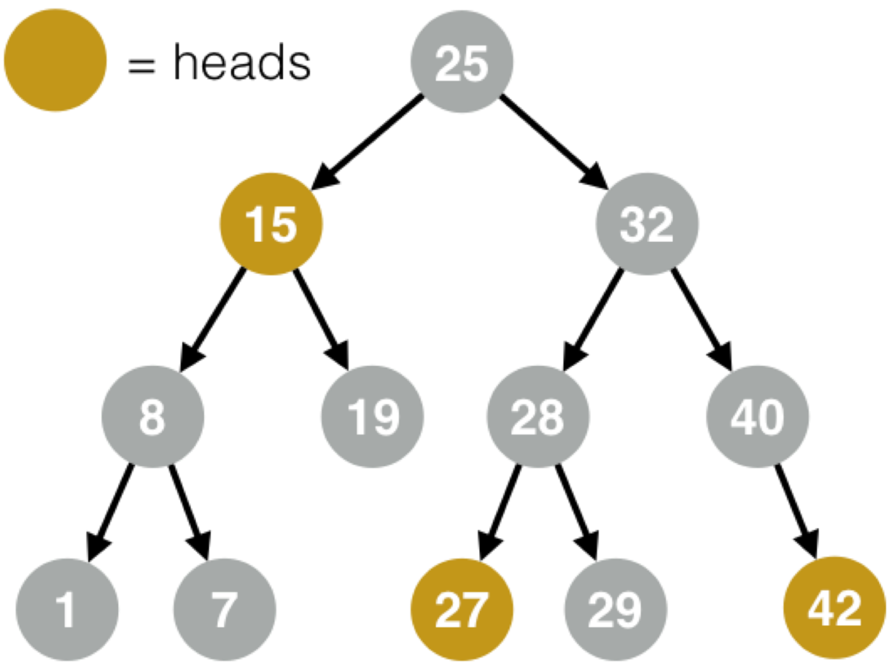


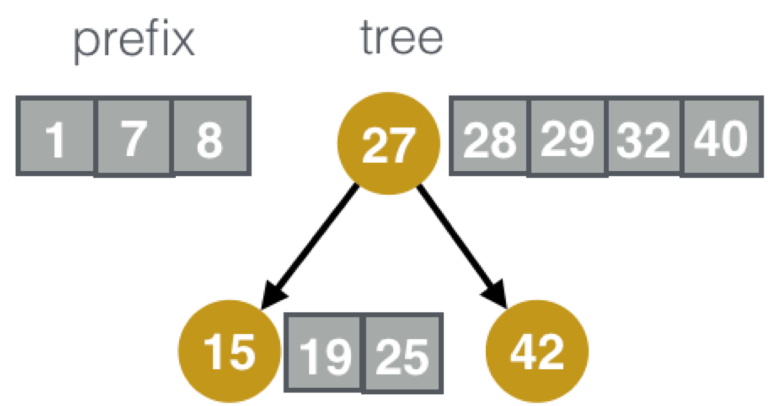
C-tree

- Purely functional **compressed** tree data structure
- Chunking parameter = B. Fix a hash function *h*.
- Select elements as **heads** with probability **1/B** using *h*.



Tree

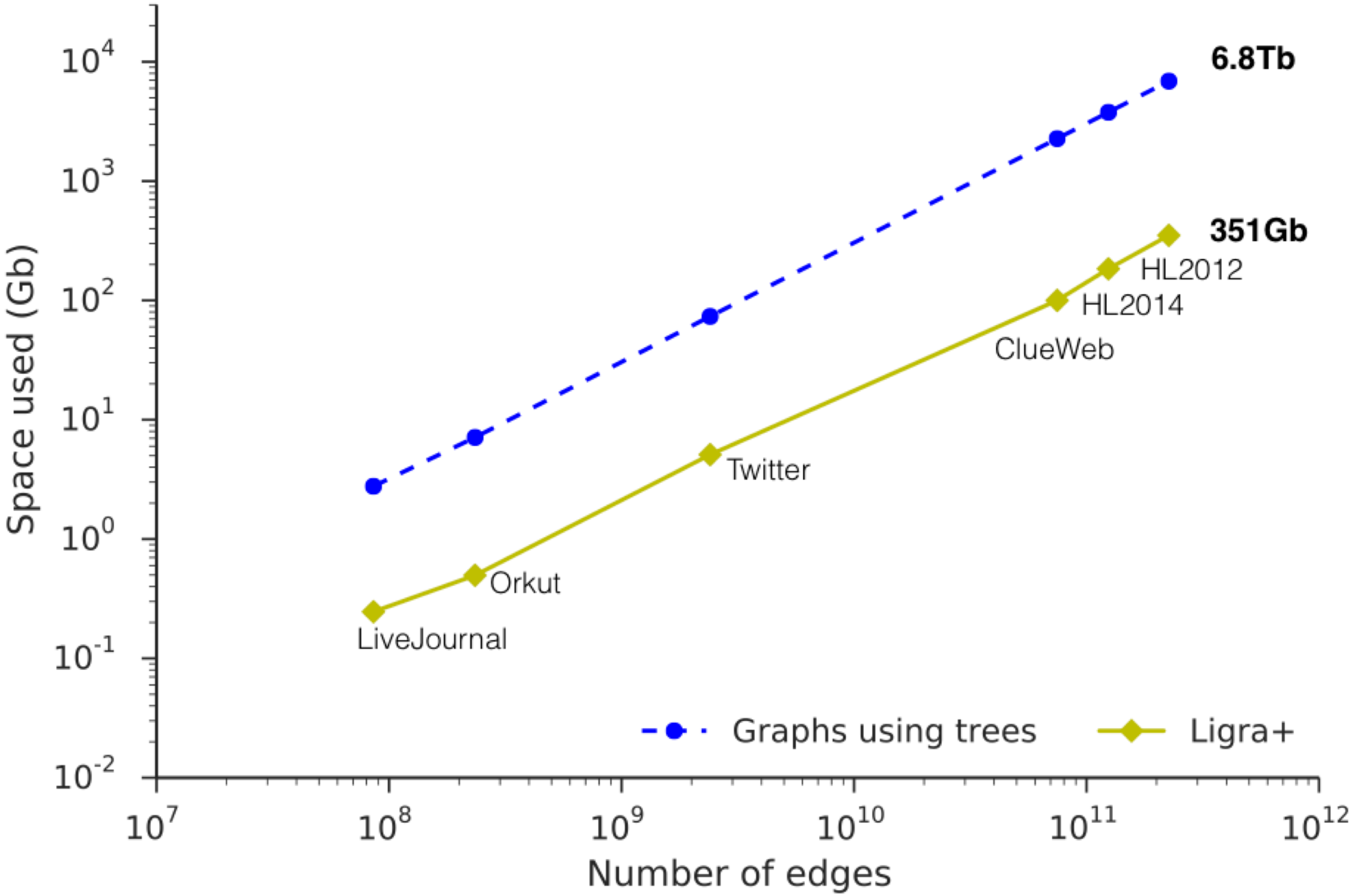
Further improve space usage for integer C-trees by difference encoding chunks



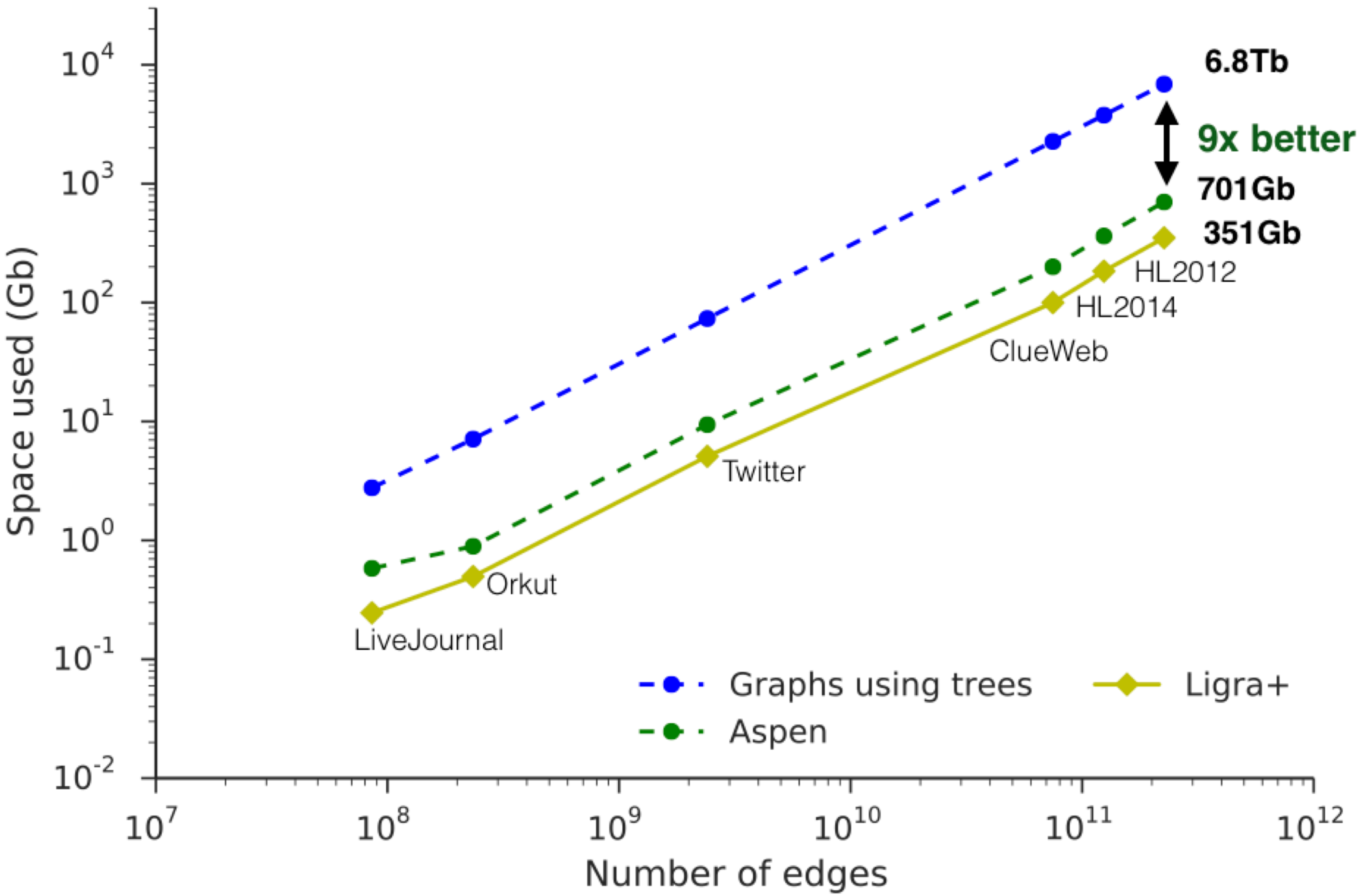
C-tree

- Supports parallel bulk insertions and deletions efficiently

Space Usage of Graphs using C-trees

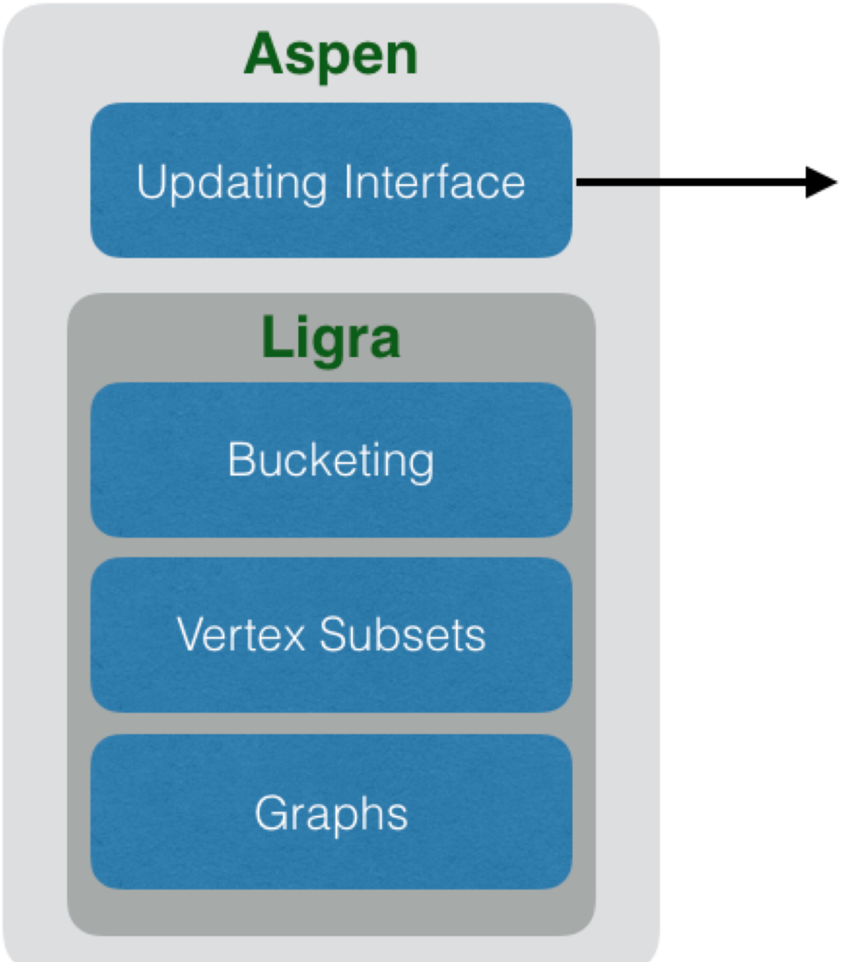


Space Usage of Graphs using C-trees



Aspen Framework

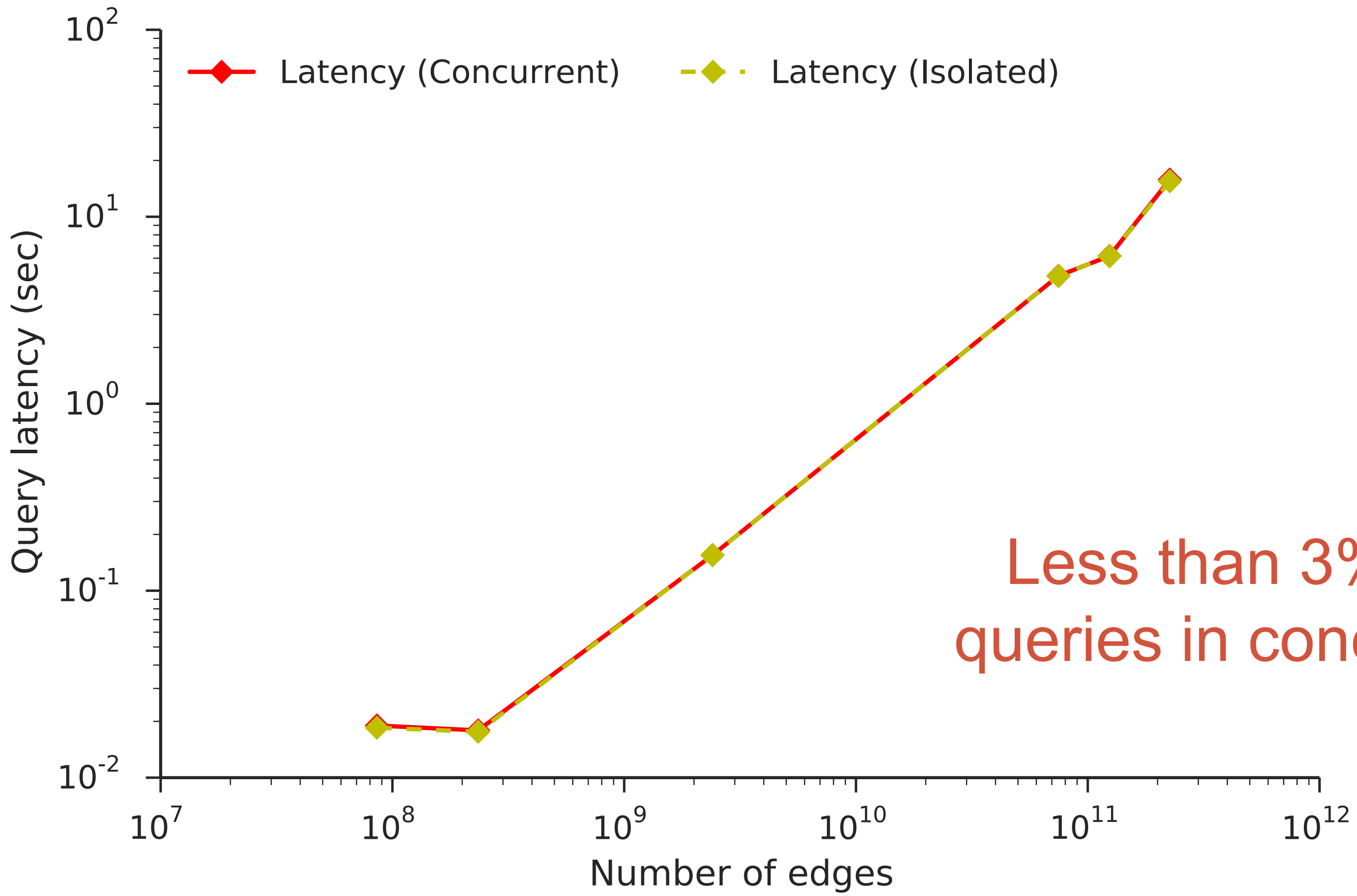
- Extension of Ligra with primitives for **updating graphs**
- Supports single-writer multi-reader concurrency



versioned graph
acquire()
release(G_s)
multi_insert(E_B), multi_delete(E_B)
...

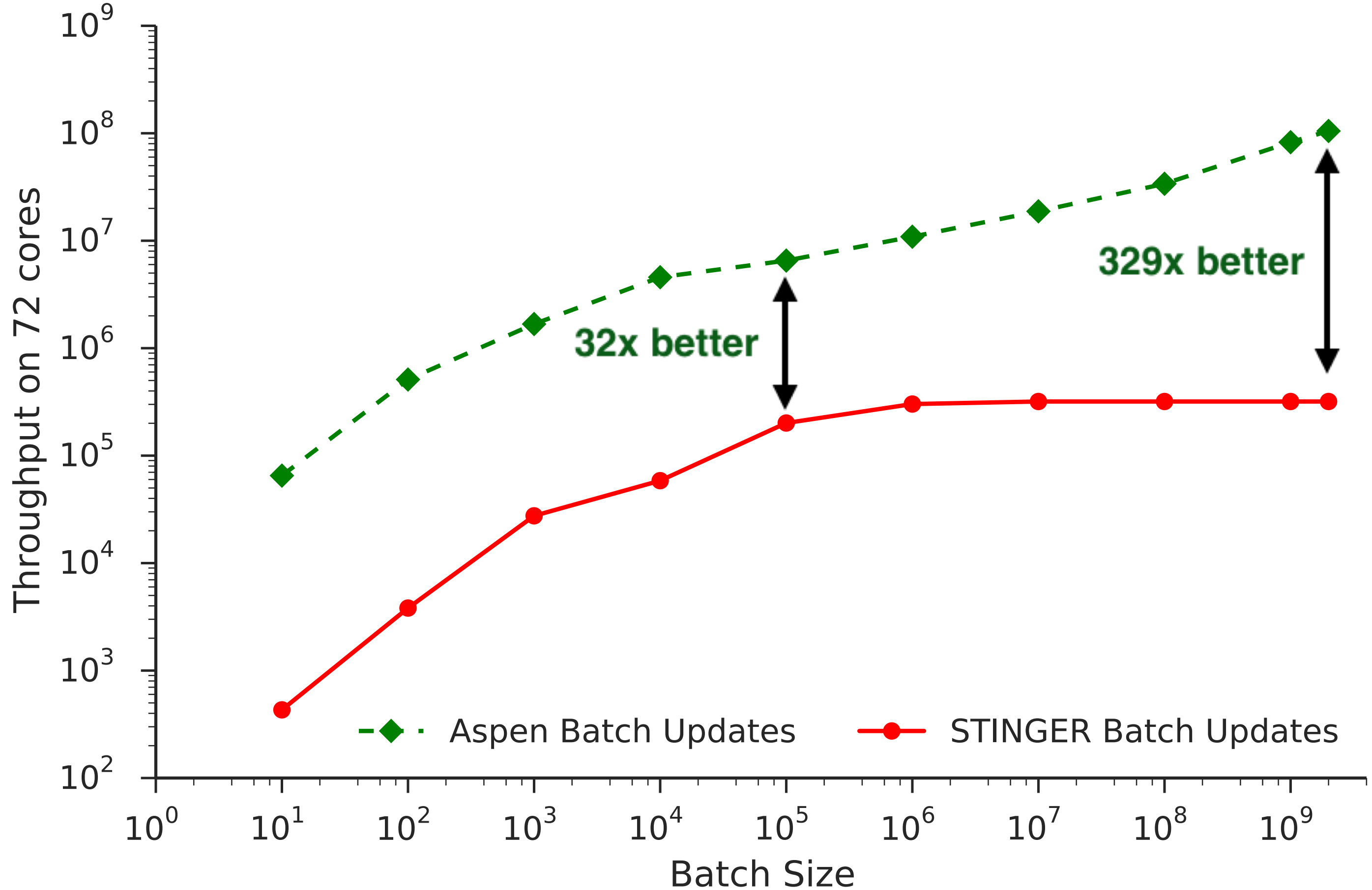
Concurrent Queries and Updates

- 72-core hyper-threaded machine with 1TB RAM
- 1 hyper-thread updating graph while remaining hyper-threads running parallel BFS



Less than 3% impact on queries in concurrent setting

Parallel Batch Updates



- Aspen processes the Hyperlink 2012 graph at over 100M edge updates per second
- About 1.4x faster than GraphOne (developed concurrently and independently) based on a rough comparison

Conclusion

- Aspen: a framework for streaming graph processing using purely functional trees
  - Code online: https://github.com/ldhulipala/aspen/
- Current bounds for C-tree are randomized
  - Ongoing work on designing a deterministic version
- Aspen for external memory or other settings
- Lots of papers on individual dynamic graph algorithms (mostly sequential, a few parallel)
  - Ongoing work: parallel dynamic graph algorithms
  - Open question: design a high-level parallel programming framework
  - Bigger open question: design a framework for dynamic graph algorithms in the streaming setting