Lazy Analytics: Let Other Queries Do the Work for You

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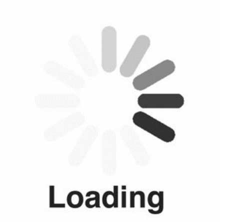
Two Common Types of Queries

- Small queries that must be answered quickly
  - High priority, latency sensitive tasks
  - Fetching data for page loads
  -

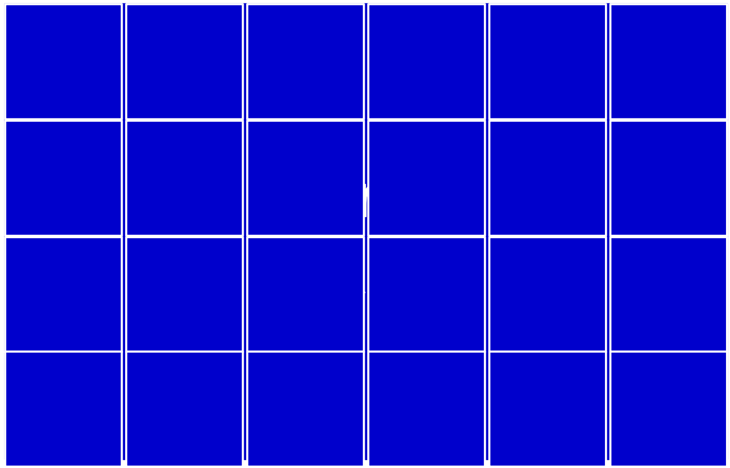


- Large analytic queries
  - Might take several hours in the best case
  - Can be delayed without harming their value to the business
  - Scanning customer databases to identify fraud patterns

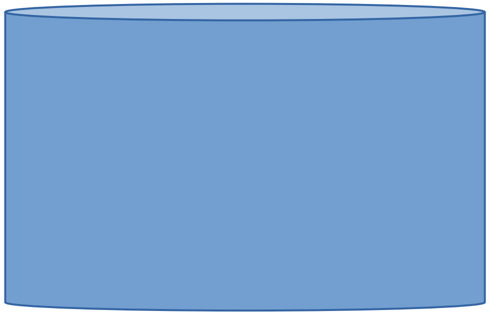
Problem: Queries Compete for I/O

- Large queries delay latency-sensitive tasks
  - Does not make sense to run both types of queries on the same machine
- Independent large queries do not benefit from shared working

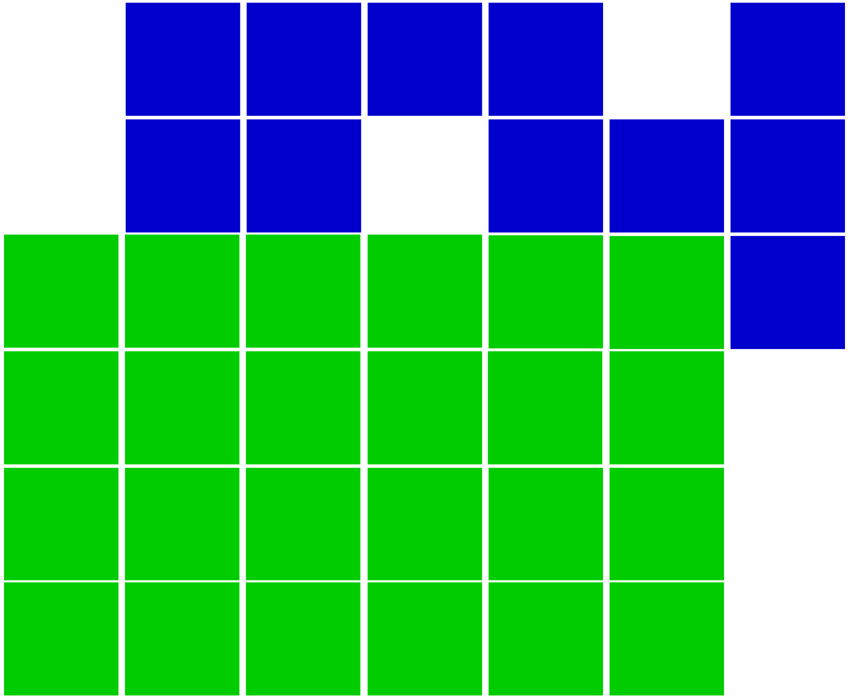
Ideal System



- Independently schedule sub-parts
- of large operations
- Piggy-back I/O on other tasks



Ideal System



- Independently schedule sub-parts
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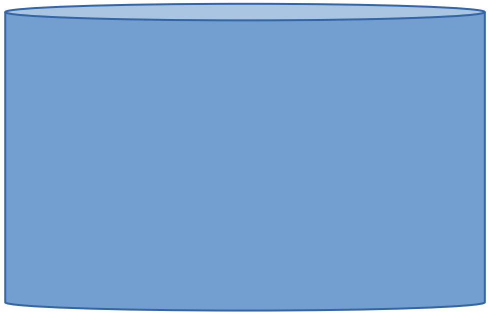
- Piggy-back I/O on other tasks
- Schedule related tasks together



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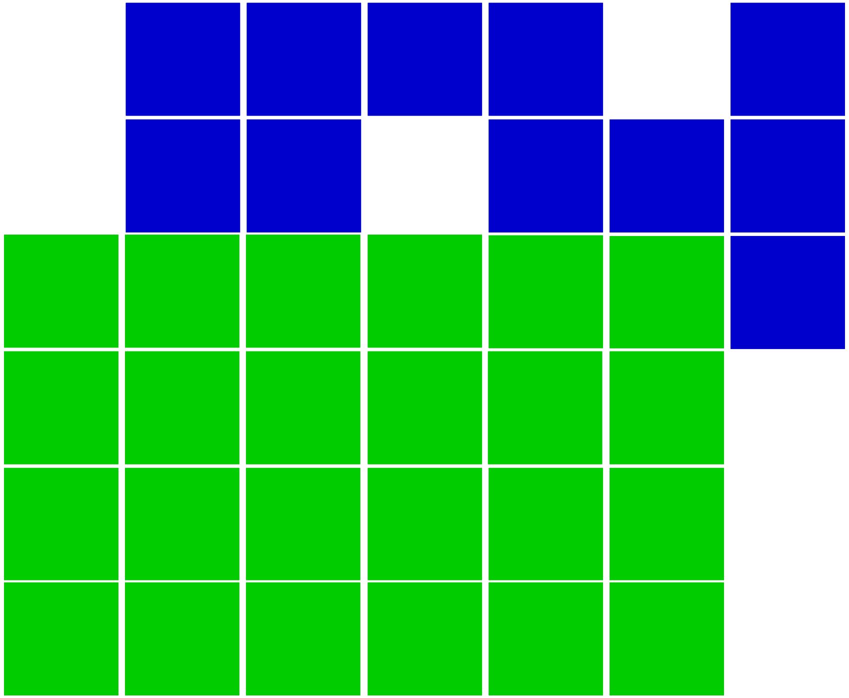

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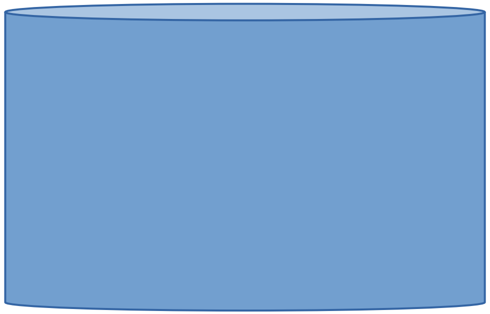


Ideal System

- Flexibility to schedule sub-parts of large tasks opportunistically
- Maximizes benefits of caching
  - Large tasks should piggy back on I/O of small tasks
  - Tasks should share working sets when tasks overlap
- Use MVCC to provide transactional semantics

Insight: write-optimized dictionaries already implement this functionality for writes.

Derange Queries

Give to queries the I/O savings that write optimization gives inserts

- Piggyback I/O on other operations
- *Can* execute lazily
  - System has flexibility to defer tasks until convenient or required
  - Can schedule parts of queries independently
  - Still operate on a snapshot of the data consistent with query time

In Rest of This Talk

- The derange query model with an example
- How to encode queries as “inserts” in a write-optimized dictionary
- Some asymptotic performance analysis (DAM Model)
- Particularly beneficial use cases

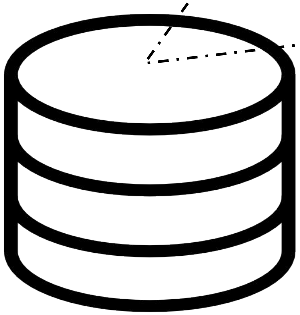
derange(**R**, **Filter**, **Map**, **Fold**, **k**)

- **R** - the input range
- **Filter** - predicate to remove records that do not meet a criteria
- **Map** - function to apply to each record
- **Fold** – commutative, associative function to propagate results
- **k** – (key, value) pair where results are accumulated

Derange queries map a function over a range of records and lazily aggregate the results.

Example: Online Marketplace

```
Item {
  productId : num
  warehouse : address
  quantity  : num
  value     : num
  price     : num
}
```



Inventory Database

Example: Online Marketplace

derange(**R**, **Filter**, **Map**, **Fold**, **k**)

What is the total value of all products stored in NY warehouses?

- **R** = (-∞,∞)
- **Filter** = { return Item.warehouse != NY }
- **Map** = { return Item.quantity * Item.value }
- **Fold** = { totalValue += result }
- **k** = “InventoryAt||TIMESTAMP”

```
Item {
   productId : num
   warehouse : address
   quantity  : num
   value     : num
   price     : num
}
```

Inventory Database

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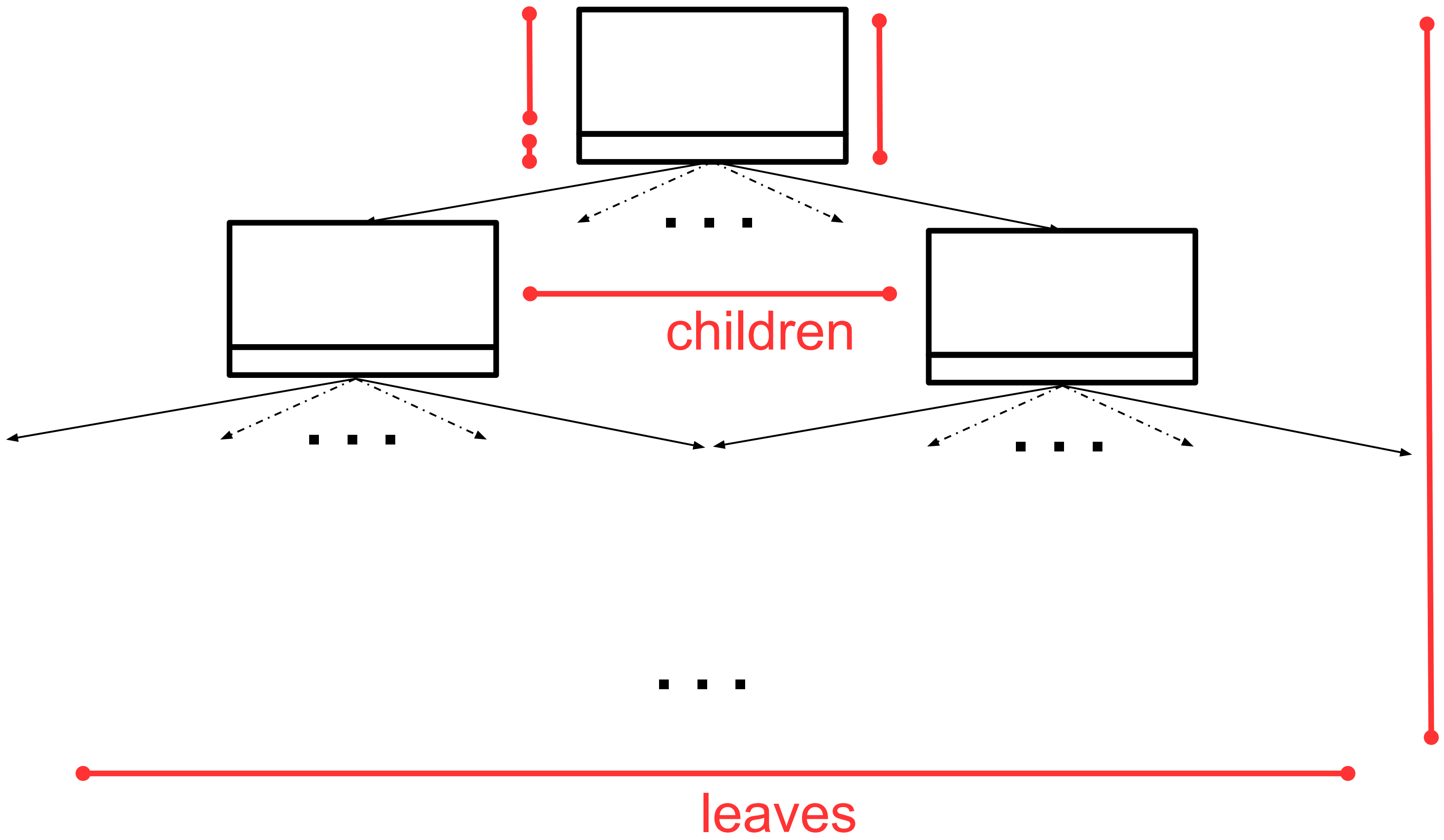
Write-optimized Dictionaries

- High performance indexes by aggregating updates
  - Lookup performance is comparable to traditional data structures
  - Inserts are orders of magnitude faster
- Used by some of the fastest databases[1] and file systems[2] to speed up writes
- B^{ε}-Tree is an ideal candidate for implementing derange queries

[1] LevelDB, HBase, Cassandra, TokuDB,

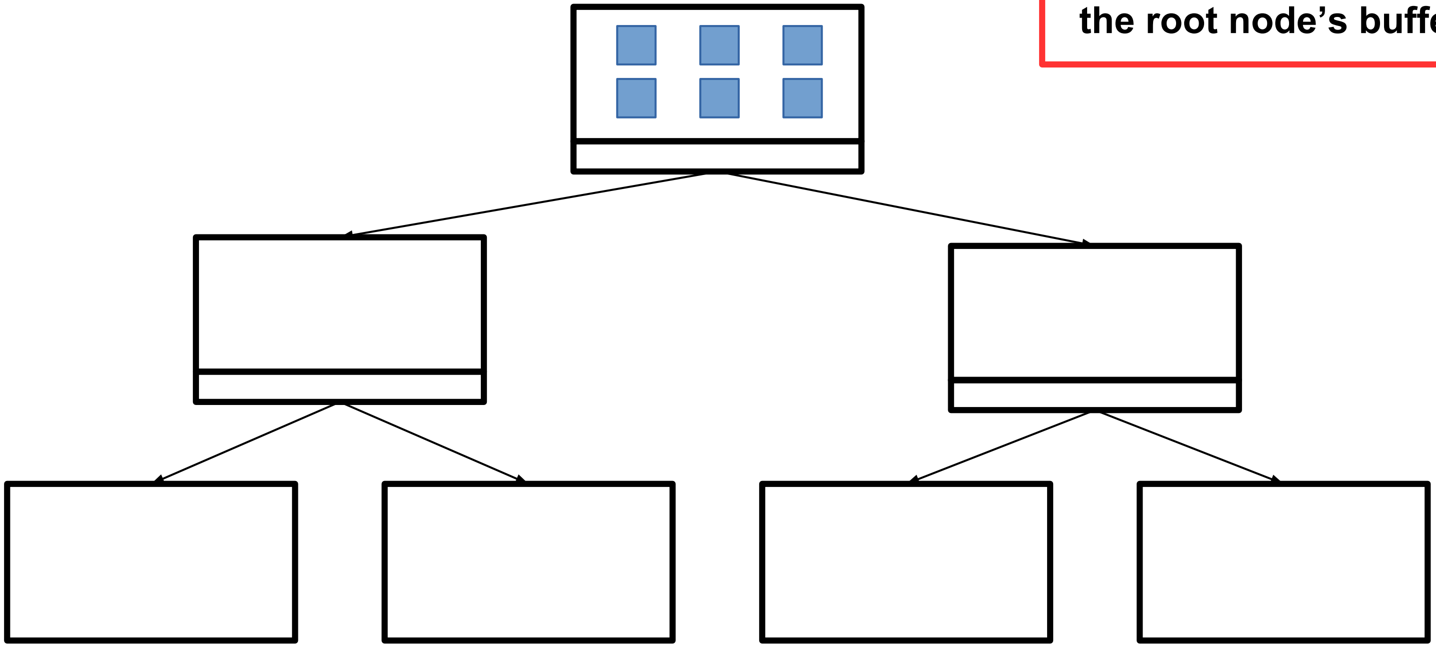
[2] TableFS, KVFS, TokuFS, BetrFS

B^{ε}-Trees Are a Better Search Tree

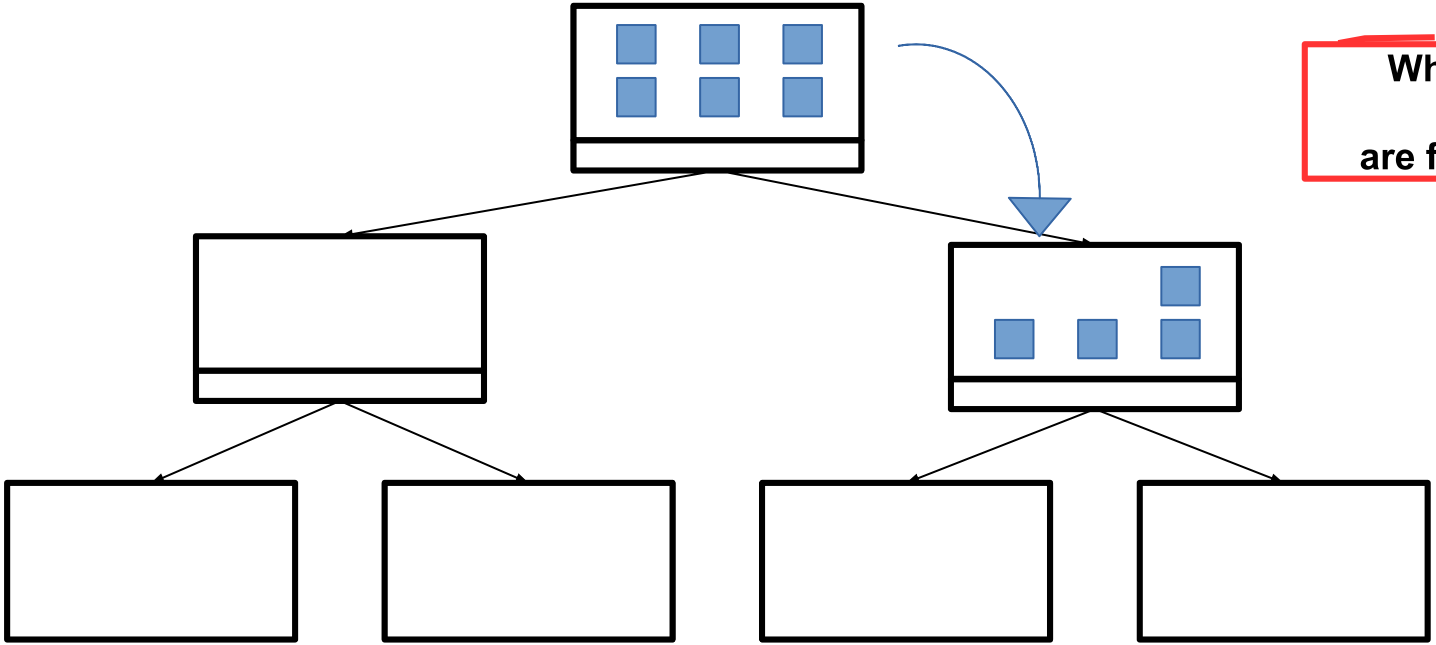


B^{ε}-Trees

All data is inserted to the root node's buffer.

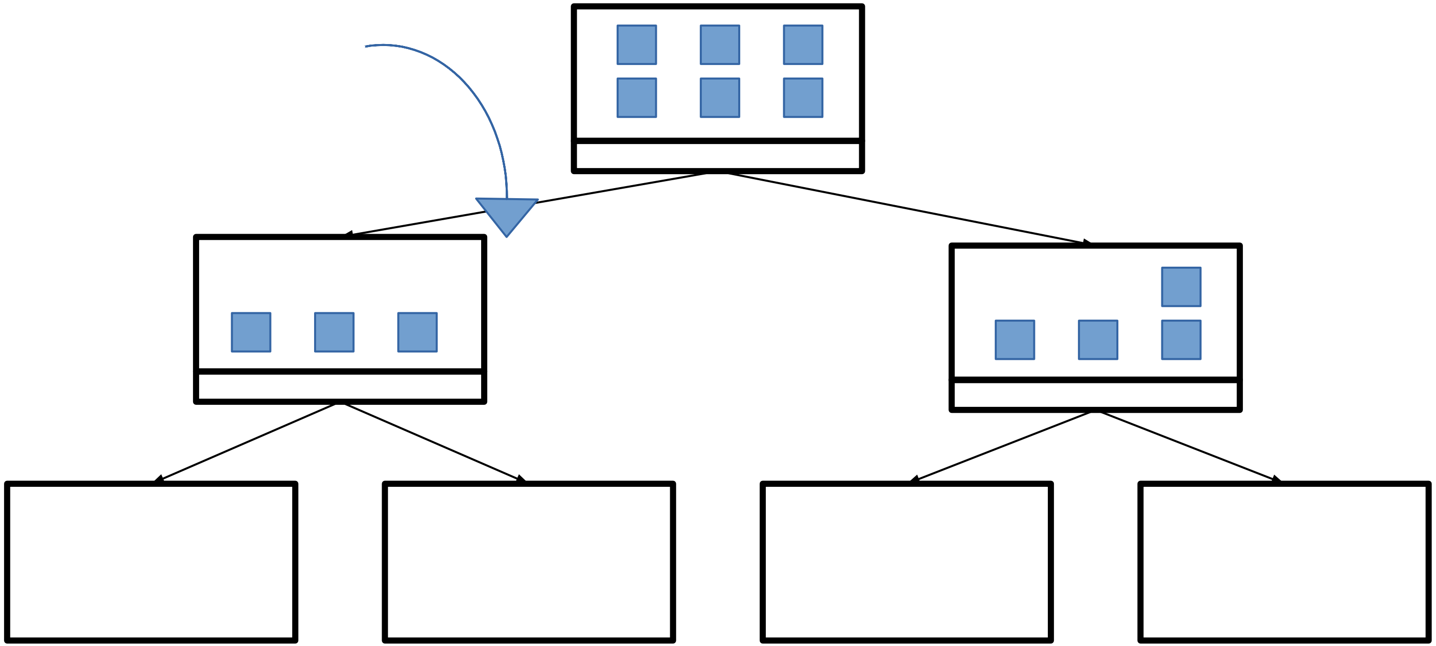


B^{ε}-Trees

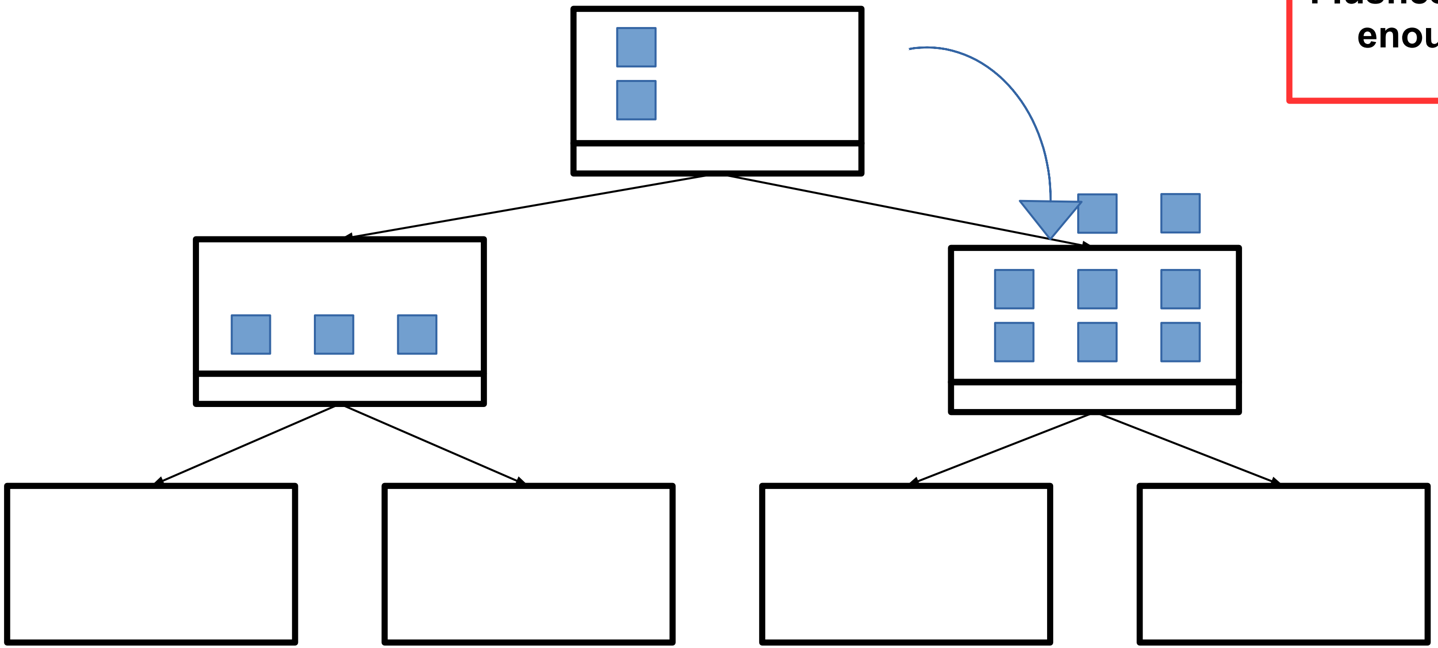


When a buffer fills,
contents
are flushed to children

B^{ε}-Trees

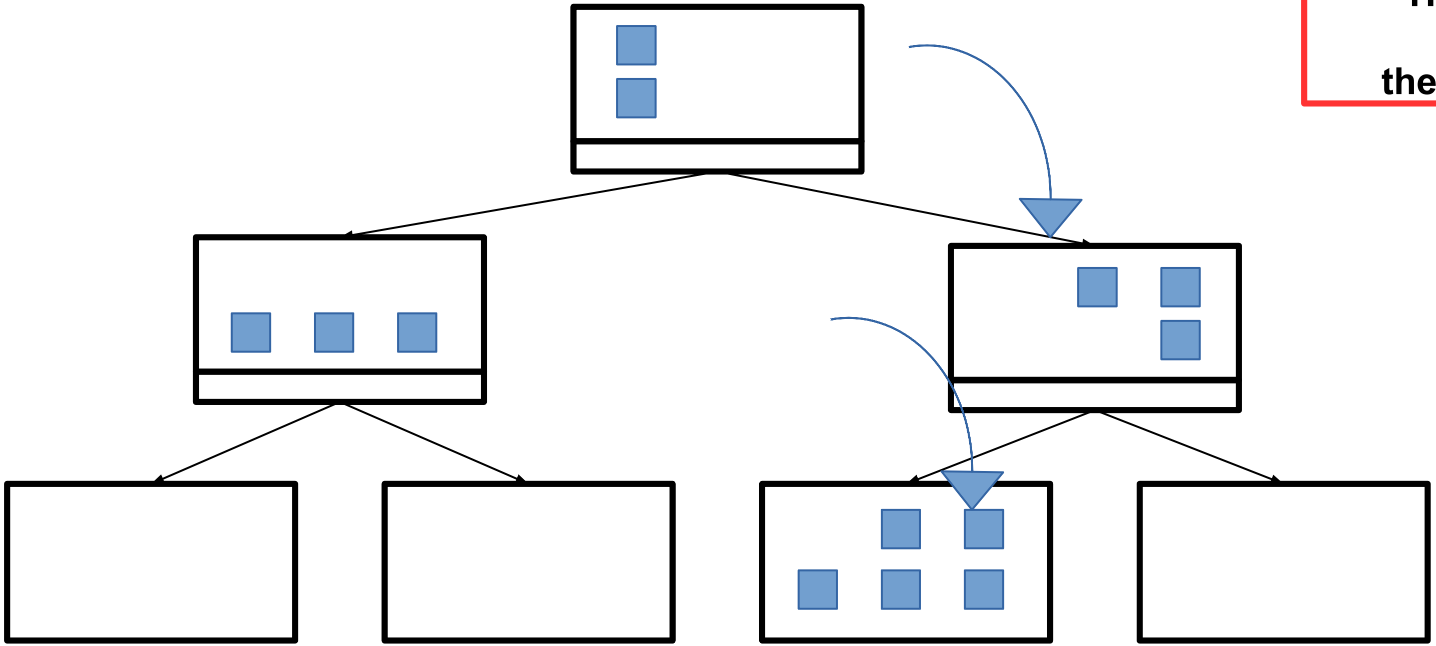


B^{ε}-Trees



Flushes can cascade if not enough room in child nodes

B^{ε}-Trees

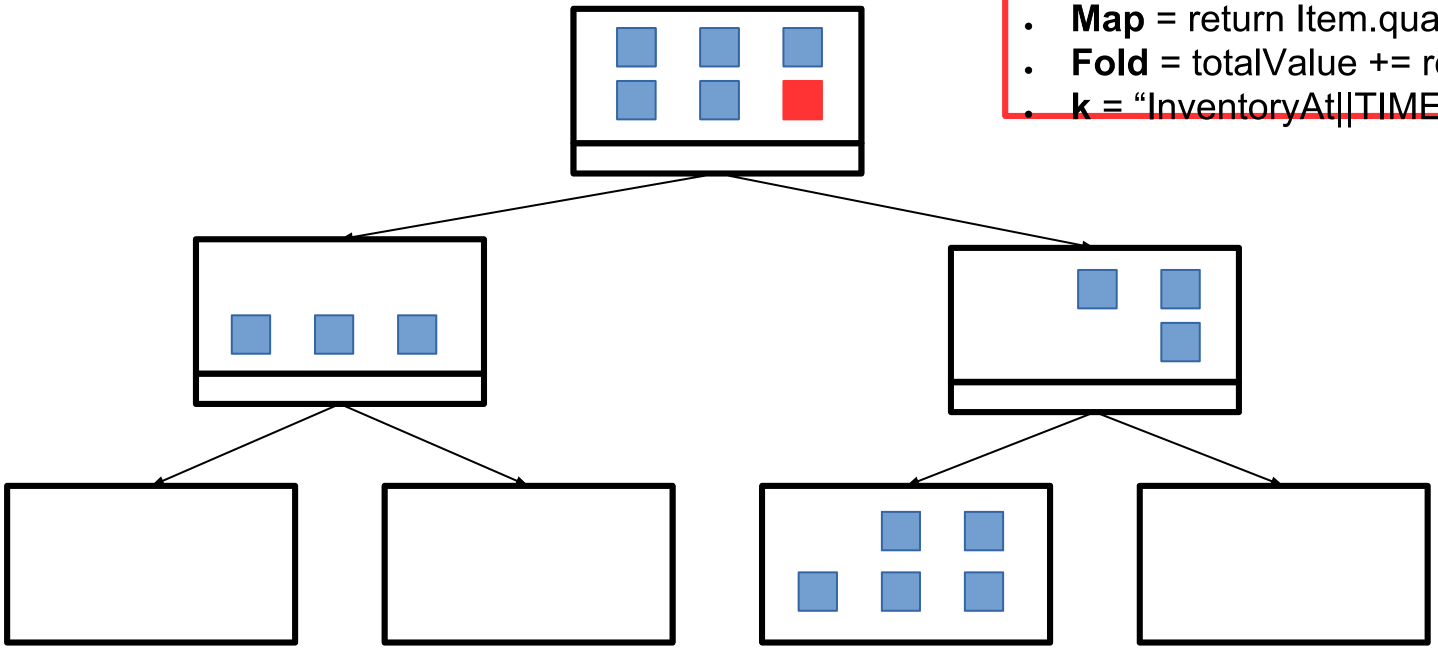


Height in the tree preserves the order of updates

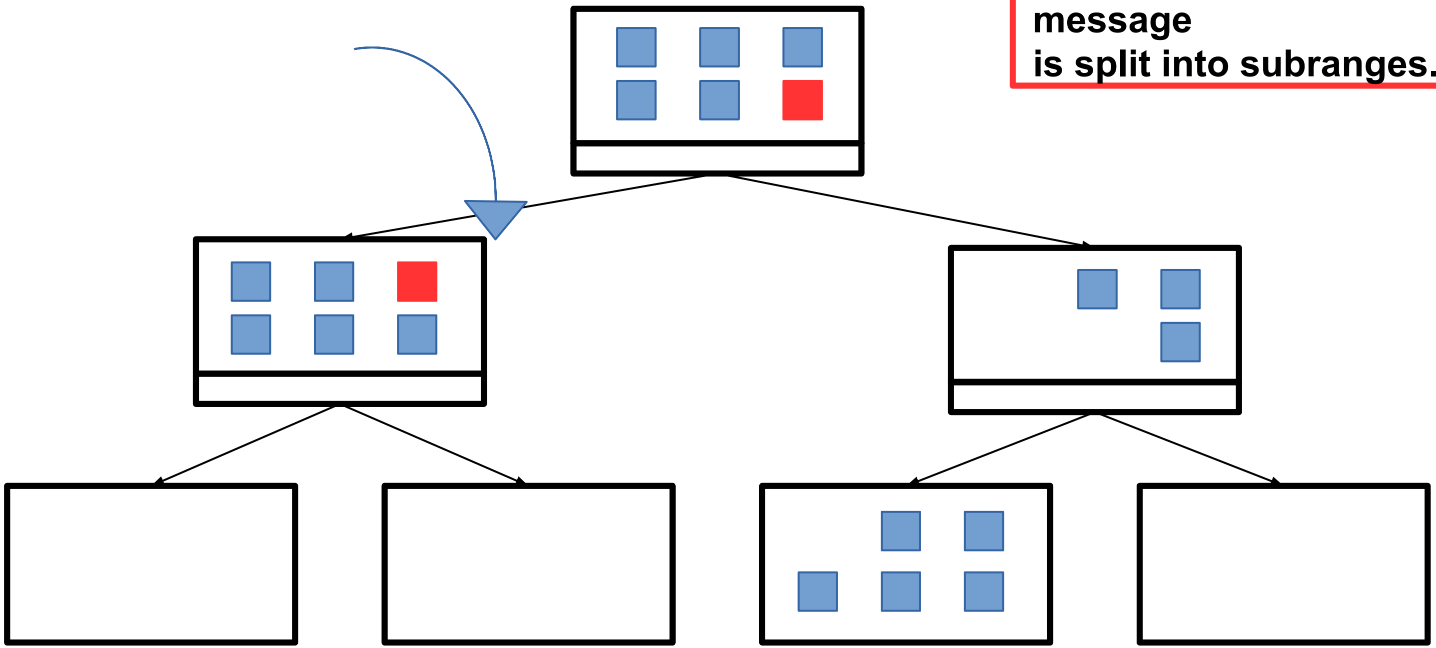
Bε-Trees

derange**(R, Filter, Map, Fold, k)**

- **R** = (-∞,∞)
- **Filter** = return Item.warehouse == NY
- **Map** = return Item.quantity * Item.value
- **Fold** = totalValue += result
- **k** = “InventoryAt||TIMESTAMP”

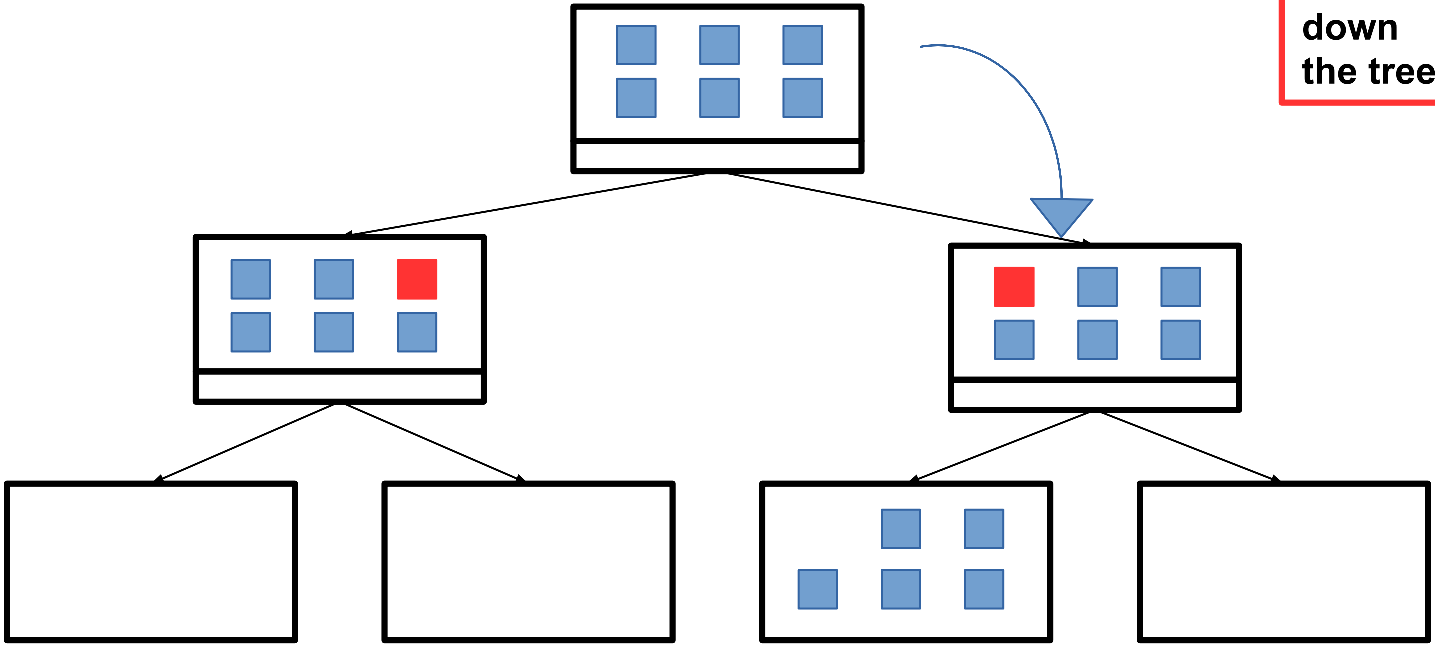


B$^{\varepsilon}$-Trees



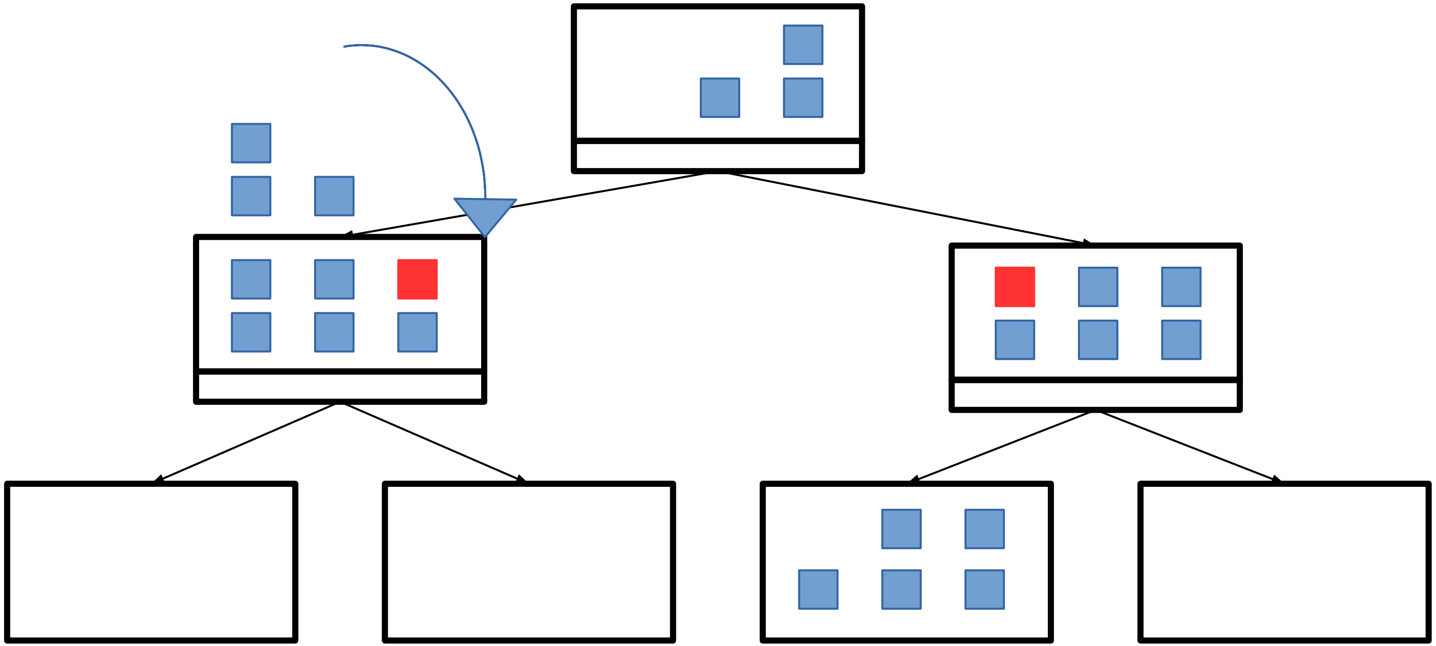
During a flush, the message is split into subranges.

B$^{\varepsilon}$-Trees

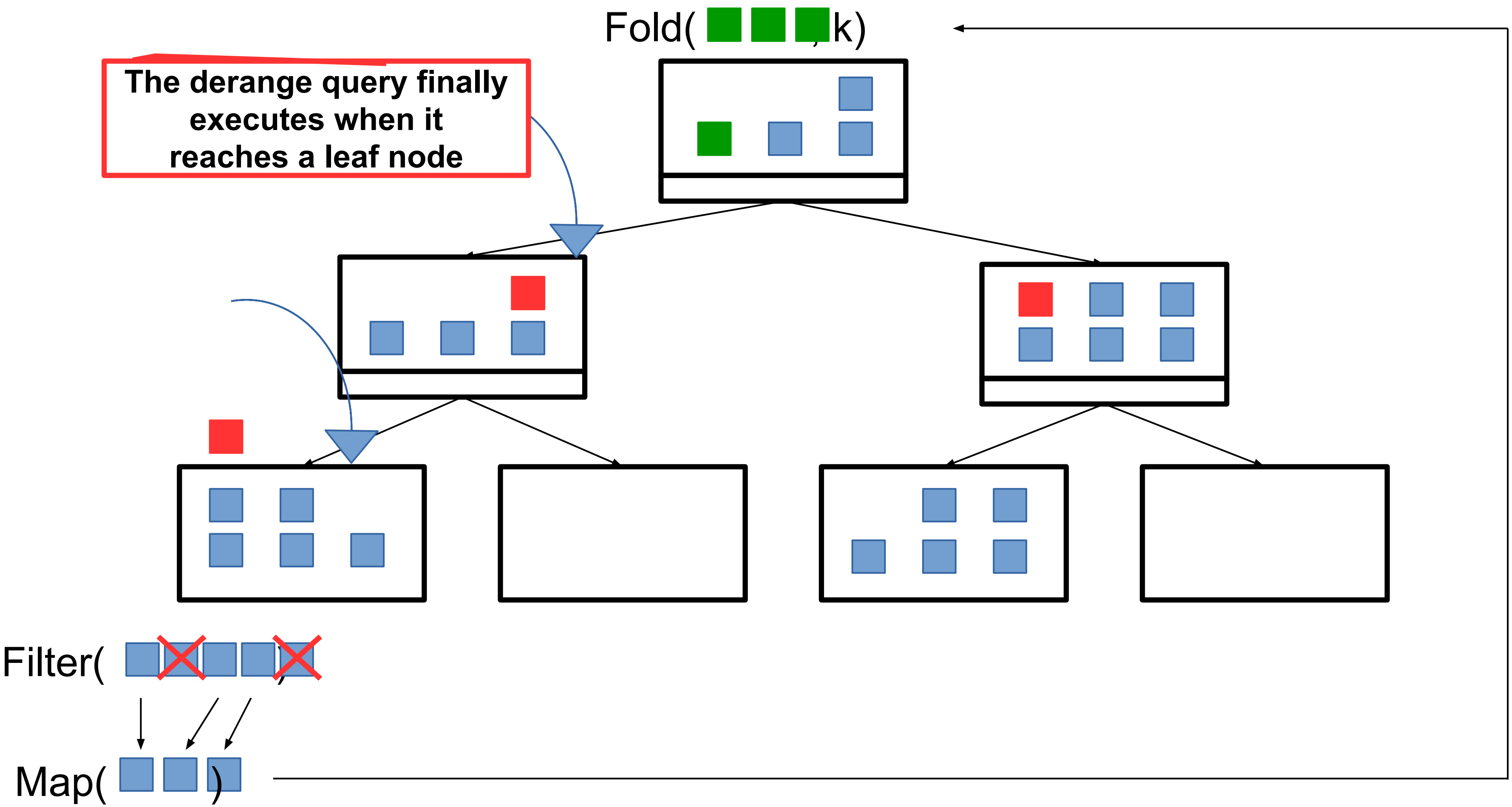


**Each subrange moves down
the tree independently.**

B^{ε}-Trees



B^{ε}-Trees



B^{ε}-tree + Derange Query Recap

- Inserts are buffered in the root and flushed from node to node
  - Many application-level updates are aggregated into each I/O
- We can encode a derange query as an “insert” message
  - Treated like any other message within the tree
  - Evaluated when they reach a leaf node
- Derange queries split and travel down the tree independently
- Results are lazily folded into the final result

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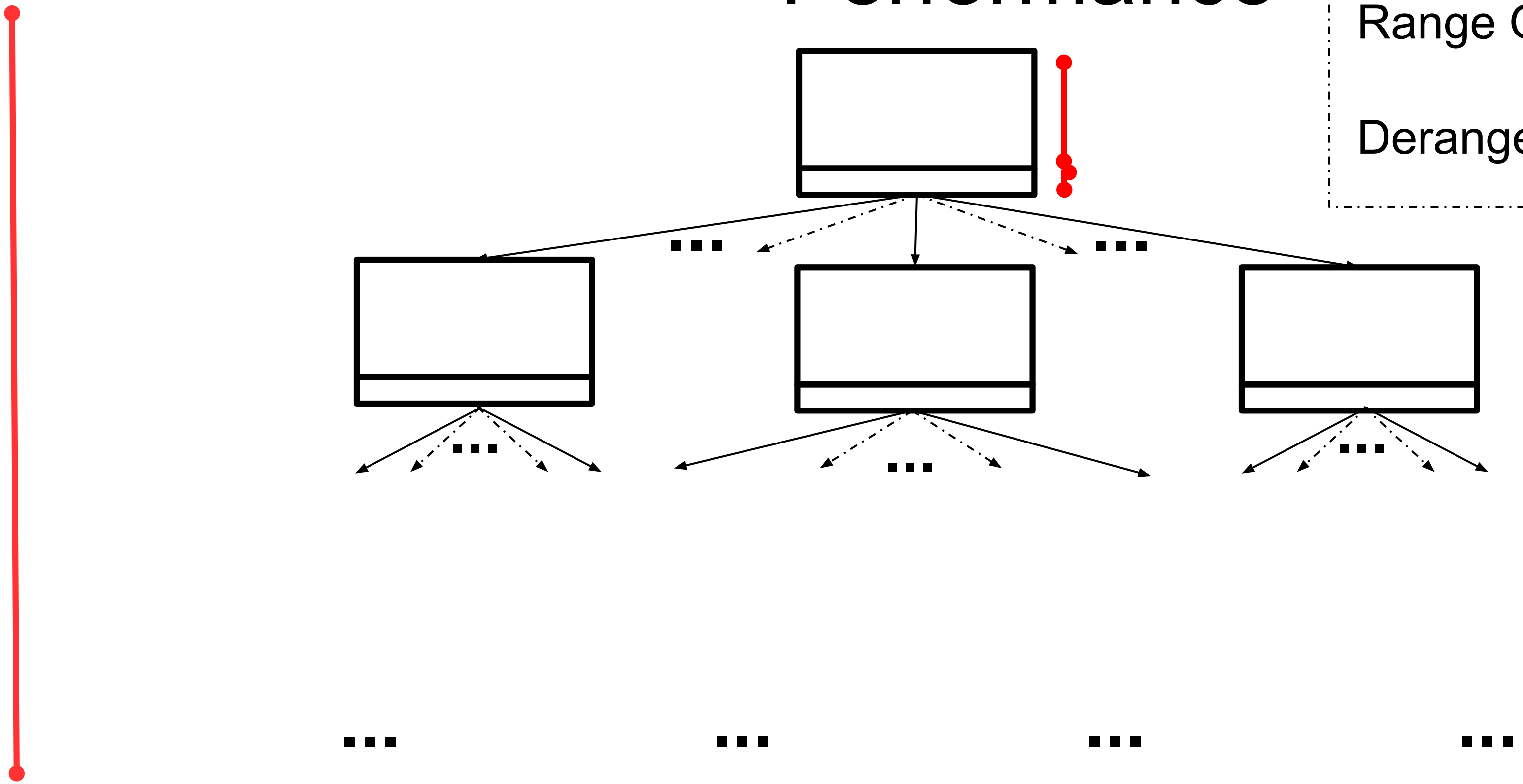
Performance



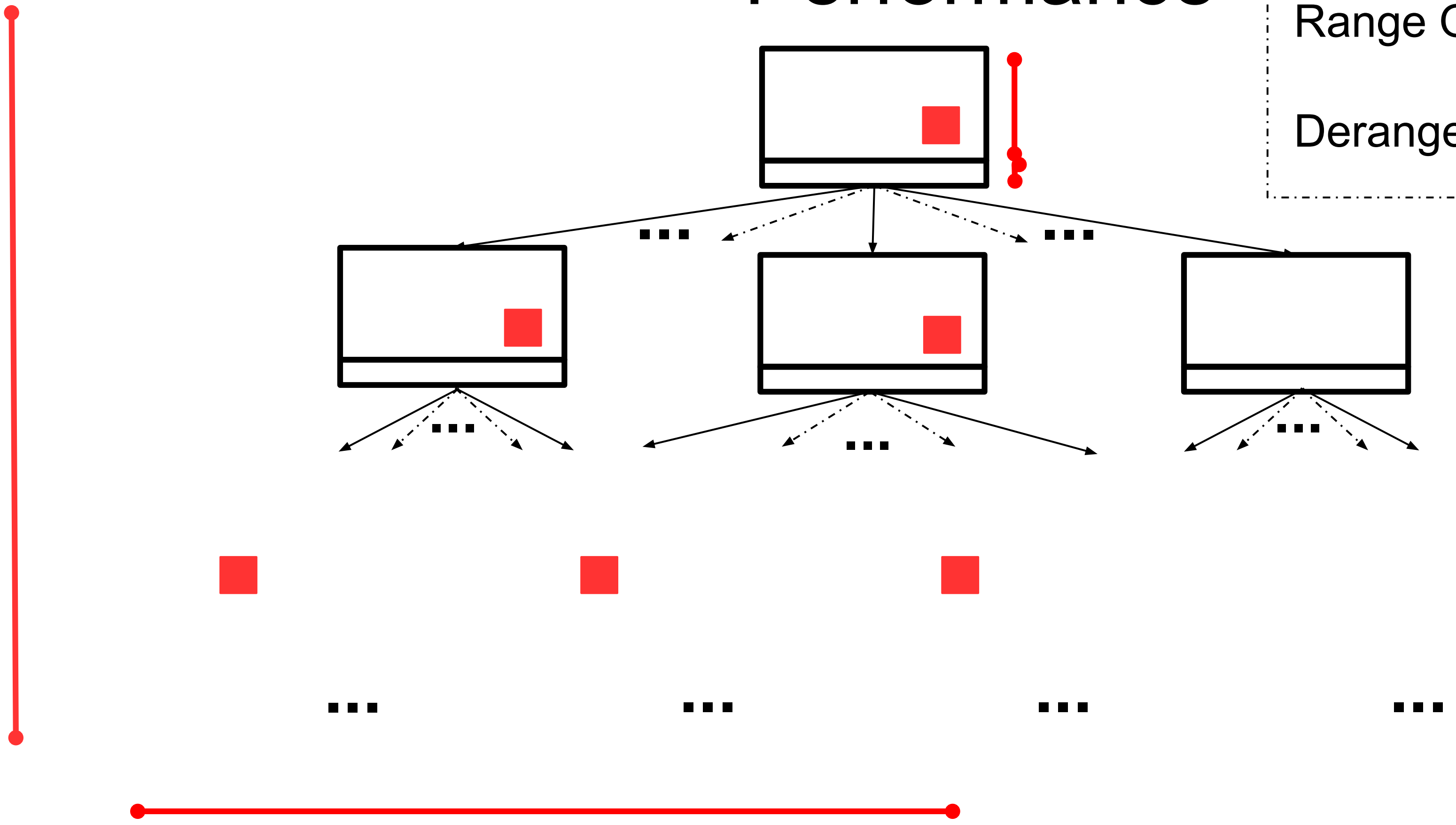
Point Query:	???
Range Query:	???
Derange Query:	???

Performance

Point Query:

Range Query:

Derange Query: ???



Asymptotic Analysis Recap

- The **batching factor** ($B^{1-\varepsilon}$) *divides* the insert cost
- By encoding queries as inserts, we bring these gains to queries
- Analysis is specific (query is allowed to take arbitrarily long)
  - Plan to generalize

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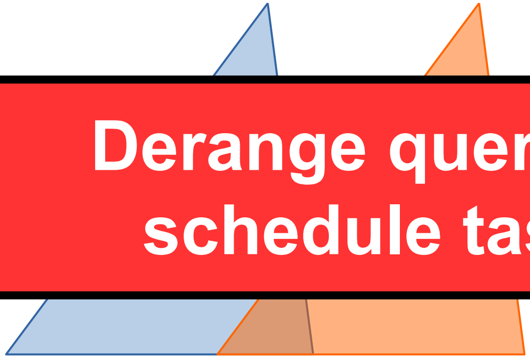
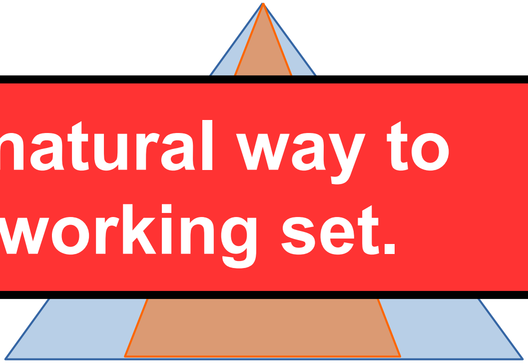
Opportunity: Overlapping Ranges

- Queries with overlapping ranges travel down the tree together

Derange queries are a natural way to schedule tasks by to working set.



Partial Overlap



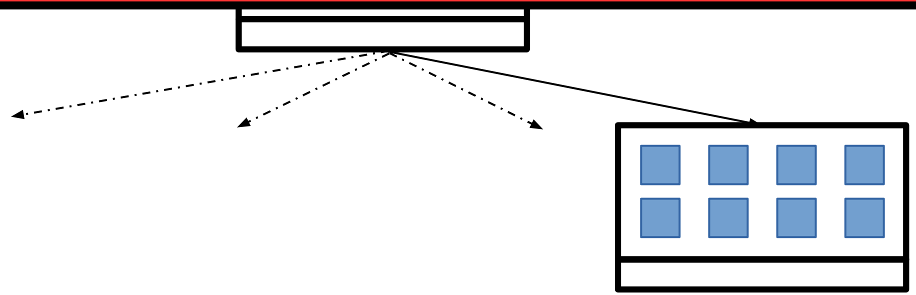
Complete Overlap

- Beneficial scheduling is transparent to application
- \- Removes complexity of query planning

Opportunity: Fine Granularity Reporting

- Efficient point-in-time computations
  - Even if work is deferred, computations are done on the view of the data at the time that the query was issued
- If data hasn't changed, 1 I/O satisfies all queries

Derange queries can increase the granularity of reporting at low cost.



Takeaways

- We can use write-optimization to reduce the cost of queries
- Low-cost analytics without harming latency-sensitive operations
- Asymptotic analysis for some cases (more work to be done)
- Exciting opportunities for scheduling and workload management