SIGMOD 2024

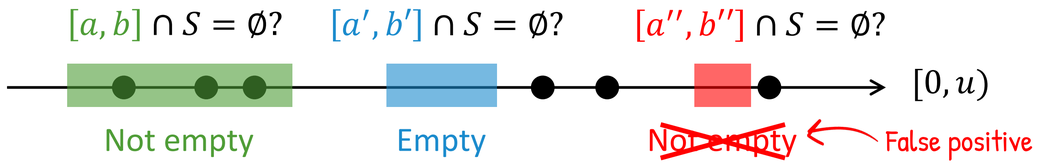
Grafite: Taming Adversarial Queries with Optimal Range Filters

Marco Costa, Paolo Ferragina, Giorgio Vinciguerra

Università di Pisa

Range Filters

Given a set S of n keys, a range filter is a space-efficient data structure that answers range emptiness queries with a false positive probability of at most ε



- Generalises Bloom filters from point to range queries
- Reduces I/Os of range queries in LSM-based storage engines

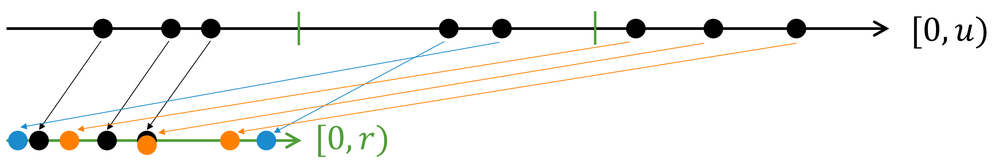
Grafite: An Optimal Robust Range Filter

1. Apply a locality-preserving hash function to the keys

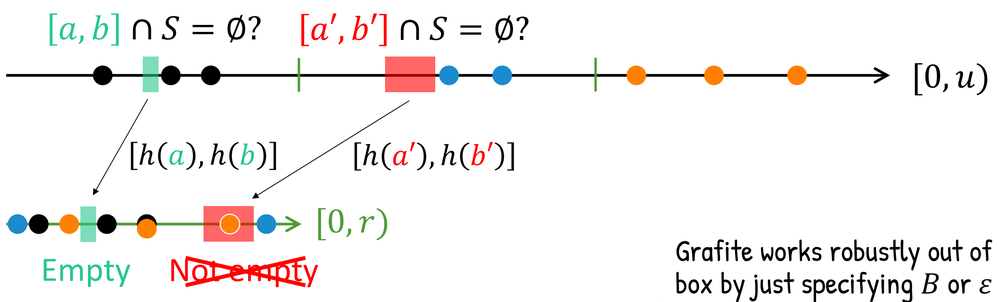
2-independent hash function

$$h(x) = \left(x + q(\lfloor x/r \rfloor)\right) \bmod r$$

Properly chosen to bound FPR and space



2. Compress the hash codes with the Elias-Fano code
3. Solve queries in hash space



Grafite works robustly out of the box by just specifying B or ε

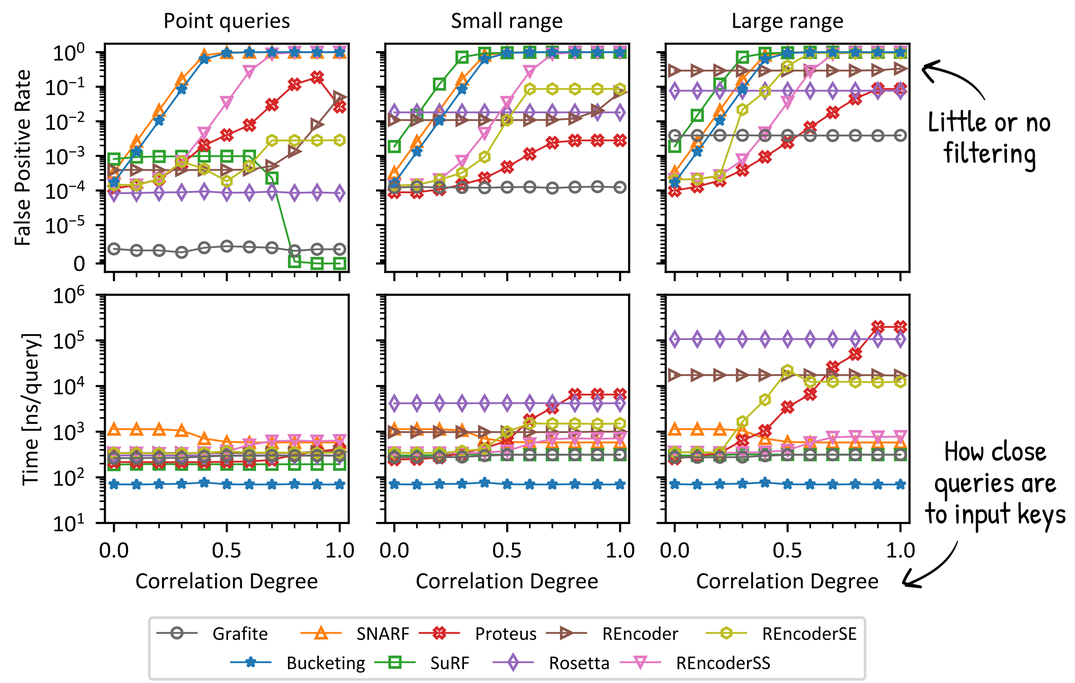
Theorem. Given a space budget of B bits/key, the query time of Grafite is $O(1)$ and the false positive probability ε is no more than $\ell/2^{B-2}$, where ℓ is the query range size

Issues with Current Range Filters

Highly complex
Sophisticated designs, hard to evaluate and deploy

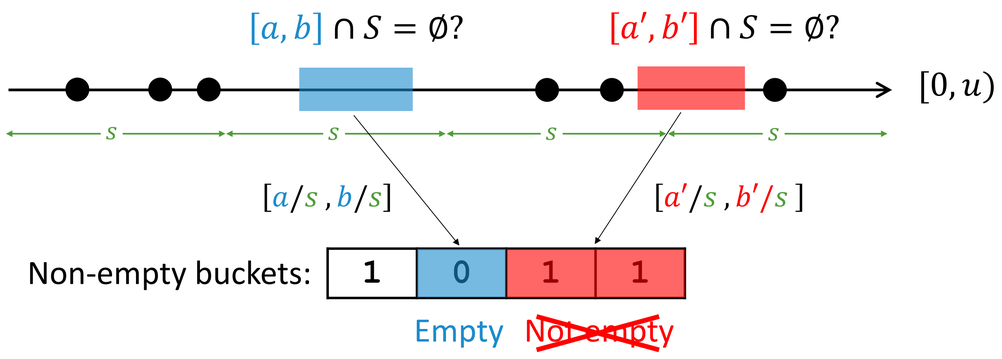
Fragile
Inconsistent FPR and query times across different datasets

Adversarial queries
Easy to issue queries that result in false positives (thus I/Os)

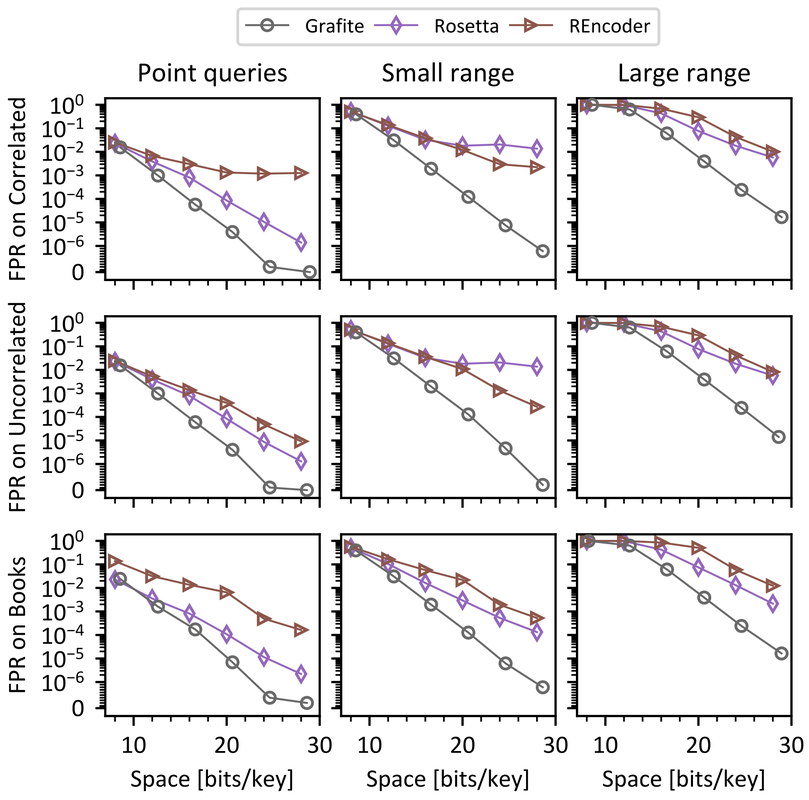


Bucketing: A Simple Heuristic Range Filter

1. Divide universe into buckets of equal size s ← Impacts FPR and space
2. Mark non-empty buckets with a compressed bit-vector
3. Solve queries by mapping ranges to bit-vector positions



Experiments with Robust Range Filters



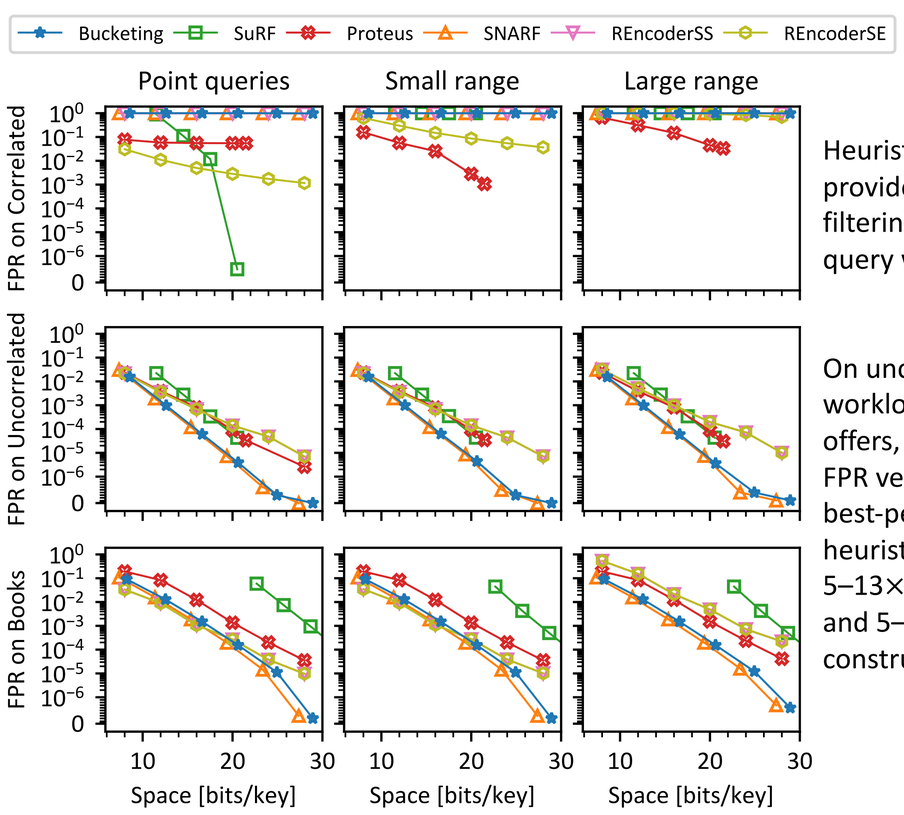
Space-vs-FPR
Grafite is up to 4 orders of magnitude more effective than REncoder, and up to 5 than Rosetta

Query time
Grafite is about 1 order of magnitude faster than REncoder, and 2 than Rosetta

Construction time
Grafite is up to 8 orders of magnitude faster than REncoder and 10 than Rosetta

Take-home message. If robustness guarantees are needed regardless of input data and future queries, Grafite is the range filter of choice

Experiments with Heuristic Range Filters



Heuristic range filters provide little to no filtering on correlated query workloads

On uncorrelated query workloads, Bucketing offers, simultaneously, FPR very close to the best-performing heuristic range filters, 5–13× faster queries, and 5–24× faster construction

Take-home message. Heuristic range filters sacrifice robustness to work well on some inputs only, but simpler solutions like Bucketing exist