Efficient Edit Distance based String Similarity Search using Deletion Neighborhoods

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Introduction

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- Given a dictionary of strings, perform fast lookups/joins of *similar* strings in the dictionary.
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- Use edit distance to quantify the notion of similarity between strings.
- Two tracks:
  1. Join: Perform self-join of strings. Given a threshold τ, list all string pairs in the dictionary with edit-distance $\leq \tau$.
  2. **Search**: Process range queries as specified in a supplied query file.

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Given a set of strings, D, and a query tuple containing a query string, q, and an edit distance threshold τ, identify all pairs $< q, s >$ s.t. $s \in D$ and $EditDistance(q, s) \leq \tau$.

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- Generate and maintain an index structure for the dictionary respecting certain time and memory constraints.
- Use the index structure to process a list of queries (2-tuples). List all *answers* in the specified format.
- **Evaluation Parameter:** Minimize total time taken to process all queries.

Problem Statement: Further Details

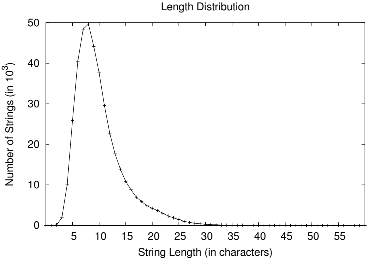
- Index construction time not counted towards the score, but must be less than 3 hrs.
- Peak memory consumption must be less than 48 GB.
- Score dependent solely on $T_{effective}$ where

$$T_{effective} = t_{end} - t_{begin}$$

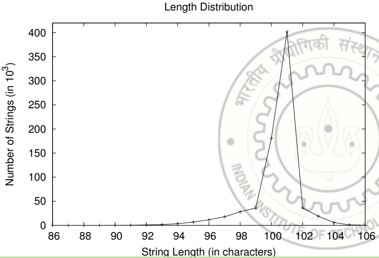
  where t_{begin} and t_{end} are time instances marking the beginning and the end of the processing of the query file, respectively.
- Evaluation environment: 8 cores, 64 GB RAM, FC 17.

The Dictionary

- Dictionary 1: Geographical names
  - Names of places from across the globe.
  - Character-set $|\Sigma|=255$
  - Mean string length $\mu=10$
  - Dictionary size $|D|=400\text{K}$



- Dictionary 2: Human genome read data
  - Strings containing human genomic data.
  - Character-set $|\Sigma|=4$
  - Mean string length $\mu=100.3$
  - Dictionary size $|D|=750\text{K}$



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- *Signature results in a filtering criteria.* **?**
  - Signature Function $SF(s)$ maps string s to a signature space.
  - Filtering condition is specific to the choice of the signature function.
  - In general, for string s, query string q, threshold τ, filtering condition is an inequality.

$$F(s, q, \tau, SF) <>\neq 0$$

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- For query $< q, \tau >$, if $ED(s, q) \leq \tau$ then $F(s, q, \tau, SF)$ must hold.
- Computation of signature should be computationally non-expensive.
- Filter condition should be tight. Resultant candidate list should be small.
- Popular signature schemes in literature:
  - Q-Gram
  - Deletion Neighborhood

Signature: Deletion Neighborhood

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- Intuition: Both strings s_1, s_2 should be reducible to a common form after at-most τ deletion operations.

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- In practice, RHS $= |q| + 1 - (\tau + 1).Q$, where q is the query string.
- For filter to be tight, RHS $> 0 \rightarrow |q| > (\tau + 1).Q - 1$.
  - Serious limitation ! For $Q = 2$, $\tau = 2$, only queries with $|q| \geq 6$ can be processed, for $\tau = 3$, $|q| \geq 8$.

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  - $|SF_{Deletion}| = \binom{|s|}{\tau} = 91$ $O(|s|^{\tau})$

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Decided to implement a system following the generic scheme and using deletion neighborhood as the signature scheme.

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- **Challenge:** Reduce space complexity of a deletion neighborhood signature based system while maintaining completeness of solution.
- Signature defined w.r.t. a threshold, need dedicated index structures, I_τ, for each threshold, $\tau = [0 : 4]$.

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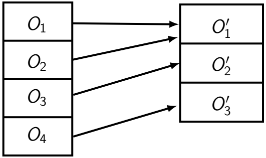

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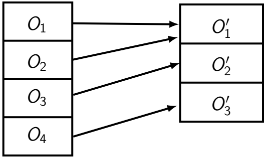

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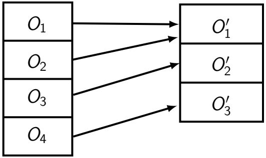

- Possible Solution ? **Hashing !**
- For $O \in SF_\tau(s)$, $h(O) = suffix_L(O)$.
  - Hashing results in a reduced set representation of $SF_\tau(s)$.
  - Ex. for $s =$"$SIGDATA$", $\tau = 1$, $L = 3$,
    - $h(SF(s)) = \{$"ATA", "DTA", "DAA", "DAT"$\}$
    - $|h(SF_\tau(s))| = 4 < |SF_\tau(s)| = 8$
- Added Benefit: Need not generate all elements in $SF_\tau(s)$. $|h(SF_\tau(s))| = O(\binom{L+\tau}{\tau})$.

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- Why suffix ?
  - No real reason. Initial design decision.
  - Performed well, stuck around.
- Possibly lucrative to try other hash functions/schemes.

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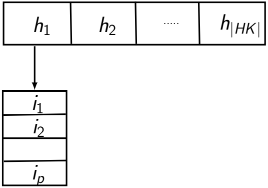

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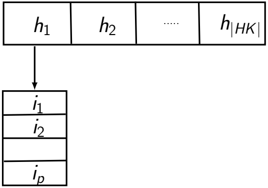

  - Keys consist of string resulting from hash (suffix operation).
  - List consists of *ids* of strings in D that generate the key.

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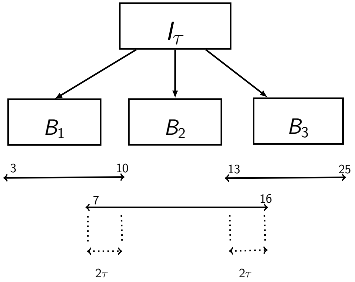
  - I_τ consists of buckets.
  - Every bucket responsible for indexing strings within a particular length range.



Bucketing: Why ?

- Ex. Let $s =$"*PLACATING*", $|s| = 9$.
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- 25% reduction in average search time for $\tau = 2$.
  $150\mu s \rightarrow 110\mu s$.

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Bucketing: Reducing collisions in Hash-Table

Partition strings on basis of length. Apply early length filtering. Results in smaller individual hash-tables. Increases space requirement.

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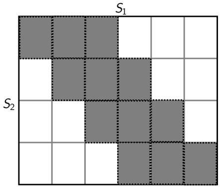

- For each row i, only need to examine j s.t. $i - \left\lfloor \frac{\tau-\delta}{2} \right\rfloor < j < i + \left\lfloor \frac{\tau+\delta}{2} \right\rfloor$. $\delta = abs(|s_1| - |s_2|)$.

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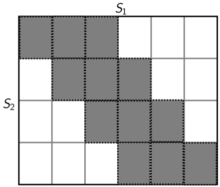

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- Li et al., VLDB 2012.

Execution

- Generate dedicated index structures, I_τ for each τ.
- Read and group all queries depending on threshold τ.
- Sequentially process queries for each $\tau = [0:4]$.
  - Multiple threads read their own queries.
  - Thread j responsible for all queries s.t. $id_q \ \% \ 8 = j$.
  - Result of each query written to a global buffer in memory. Contention between threads on memory write.
- Flush the buffer to the disk.

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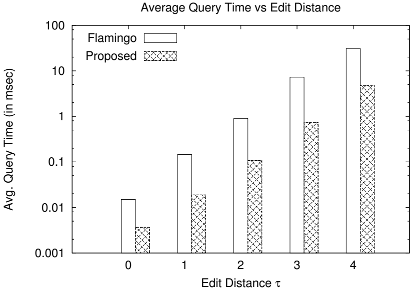

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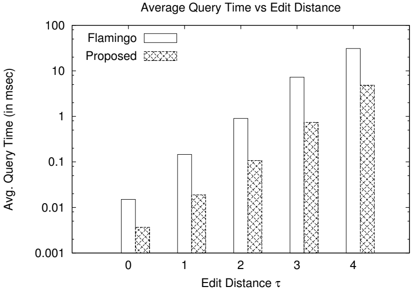

τ	Avg. query time (ms)	
	Flamingo	Proposed
0	0.015	0.004
1	0.146	0.019
2	0.901	0.108
3	7.245	0.736
4	30.906	4.801

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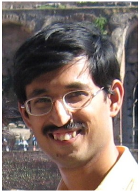

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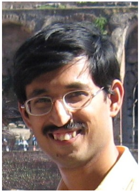

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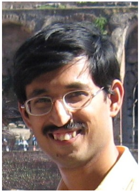

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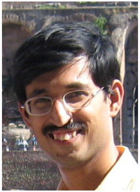

Thank You !