TraSS: Efficient Trajectory Similarity Search Based on NoSQL Databases–Appendix

A OTHER MEASURES

A.1 Hausdorff

A.1.1 Definition.

Definition 1. (*Hausdorff*).

$$D_H = \max\{\max_{i=1}^{n} \min_{t \in T} d(q_i, t),\ \max_{j=1}^{m} \min_{q \in Q} d(q, t_j)\}, \tag{1}$$

where $t \in T$ and $q \in Q$ is a point of T and Q, representatively.

A.1.2 Pruning strategies. It is easy to know that the Hausdorff distance satisfies Lemma 3. Because, $D_H \geq d(t, Q)$ and $D_H \geq d(q, T)$. All other Lemmas proposed in Section 5.3 are based on Lemma 3, so that these Lemmas can be directly used in the Hausdorff distance.

A.2 DTW

A.2.1 Definition.

Definition 2. (*DTW*).

$$D_D(Q^n, T^m) = \begin{cases} \sum_{k=1}^{m} d(q_1, t_k) & \text{if } n = 1 \\ \sum_{k=1}^{n} d(q_k, t_1) & \text{if } m = 1 \\ d(q_n, t_m) + \min\{D_D(Q^{n-1}, T^m), & \\ D_D(Q^n, T^{m-1}), D_D(Q^{n-1}, T^{m-1})\} & \end{cases}, \tag{2}$$

A.2.2 Pruning strategies. **Global Pruning.** Both Lemmas proposed in Section 5.3 can be directly used in the DTW distance. In addition, we can further prune index spaces the following Lemma:

Lemma 1. *if*

$$\sum_{bbox \in Q.B} d(index\_space, bbox) > \varepsilon,$$

then $D_D > \varepsilon$, where $d(index\_space, bbox)$ is the minimum distance of the index space and a bbox.

Proof. Because the trajectory T is completely covered by the index space $IndS$, so that the distance of each point of T to the bbox is greater than or equal to the distance of $IndS$ to the bbox. Thus, $D_D(Q^n, T^m) \geq D_D(Q^n.B, T^m.B) \geq D_D(Q^n.B, T^m.MBR) \geq D_D(Q^n.B, IndS) = \sum_{bbox \in Q.B} d(IndS, bbox)$. □

Local Filtering. Both Lemmas proposed in Section 5.4 can be directly used in the DTW distance. In addition, we can further prune index spaces the following Lemmas:

Lemma 2. *if $D_D(Q.B, T.B) > \varepsilon$, then $D_D > \varepsilon$, where $D_D(Q.B, T.B)$ is the DTW distance of the bboxes of Q and T.*

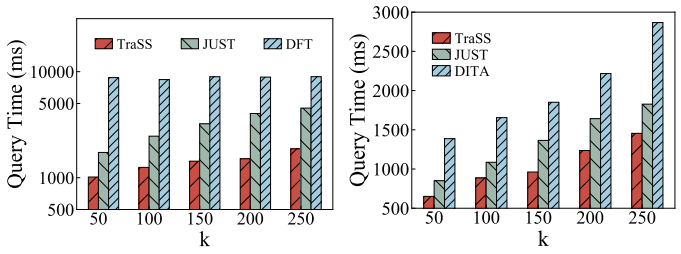
Proof. Analogy to the proof of Lemma 1. □

A.3 Efficiency.

DITA does not support the Hausdorff distance and *DFT* does not support the DTW. Figure 1 shows the efficiency of our framework. We can intuitively observe that in the Hausdorff and DTW metrics *TraSS* is more outstanding than others.

B THE ENLARGED ELEMENT

Without losing generality, we normalize the entire space range to an interval of 0-1. That is, the width and height of the entire space are both normalized to 1. We use $((x_1, y_1), (x_2, y_2))$ to represent the lower left and upper right points of a MBR, and w and h are the width and height. s stands for the quadrant sequence of the most appropriate enlarged element for the MBR, $|s|$ denotes its length and implies the appropriate resolution. Then, the width and height of that enlarged element are both $2 * 0.5^{|s|}$.



(a) Hausdorff (Tdrive). (b) DTW (Tdrive).

Figure 1: The Effect of Other Measures.

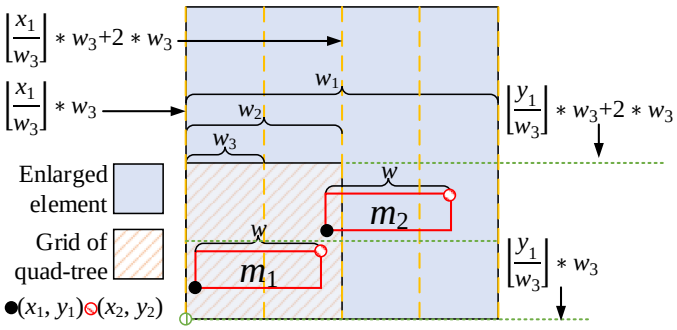


Figure 2: The Comfortable Resolution of The MBR.

Lemma 3. *The most appropriate quadrant sequence s of a MBR $((x_1, y_1), (x_2, y_2))$ has a length of*

$$|s| = l \text{ or } l + 1, \tag{3}$$

where, $l = \lfloor log_{0.5}(max\{x_2 - x_1, y_2 - y_1\}) \rfloor$.

Proof. We let $w = x_2 - x_1$ and $h = y_2 - y_1$. Without loss of generality, we presume $w \geq h$.
(1) The width of an enlarged element at l-resolution is

$$w_1 = 2 * 0.5^l = 2 * 0.5^{\lfloor log_{0.5}(w) \rfloor} \geq 2 * w. \tag{4}$$

The lower-left corner of the MBR is located in the lower-left grid of the enlarged element, and $w \leq w_1/2$, so that completely contained in that enlarged element, e.g., as shown in Figure 2, m_1 and m_2 have a width of w and locate in the orange grid. (2) The width of an enlarged element of $(l + 1)$-resolution is

$$w_2 = 2 * 0.5^{l+1} \geq 2 * 0.5^{log_{0.5}(w)+1} = w. \tag{5}$$

Thus, some MBRs with width w ($w \leq w_2$) can completely be covered in an enlarged element at $(l + 1)$-resolution, such as in Figure 2, the orange grid is also an enlarged element at $(l + 1)$-resolution, and the MBR m_1 can be completely contained by the orange grid.
(3) The width of an enlarged element of $(l + 2)$-resolution is

$$w_3 = 2 * 0.5^{l+2} < 2 * 0.5^{log_{0.5}(w)+1} = w. \tag{6}$$

Thus, any one enlarged element at $(l + 2)$-resolution can not contain the object with width w entirely.

Therefore, the appropriate resolution (also the length of the corresponding quadrant sequence) for the non-point spatial object with width w is l or $l + 1$. □

We cannot confirm the befitting resolution for the MBR only according to Lemma 3. As shown in Figure 2, m_1 and m_2 with the same width w ($w_3 < w \leq w_1/2$). However, they are contained by $(l + 1)$-resolution and l-resolution, respectively. We divide the enlarged element at l-resolution in x-axis into four equal parts according to gold dotted lines in Figure 2. Obviously,

objects which intersect more than two parts must be covered in l-resolution because any enlarged element at $(l+1)$-resolution contains only two parts. Therefore, we calculate the appropriate resolution for the object by the following inequality,

$$\lfloor \frac{x_1}{w_3} \rfloor * w_3 + 2 \cdot w_3 \geq x_2. \tag{7}$$

If Inequality (7) is "false", the object must be covered in l-resolution. At the same time, y-axis also satisfies Inequality (7). Thus, the object can be covered at $(l+1)$-resolution, only if the Inequality (7) of x-axis and y-axis are both "true". Intuitively, in Figure 2, the Inequality (7) of m_2 is "false", and the Inequality (7) of m_1 in x-axis and y-axis are both "true". Therefore, m_1 is covered in the enlarged element at $(l+1)$-resolution and m_2 is contained in l-resolution completely.

C INSTANTIATION

INSTANTIATION. We implement our framework on HBase. Figure 3 gives the architecture of *TraSS*. The *storing* component includes *calculating* XZ* index values, *extracting* DP-features, and *building puts*. Firstly, trajectories are indexed using appropriate index spaces. Then, we use Douglas-Peucker (DP) algorithm to pre-calculate DP features of trajectories to speed up query processing. After that, we convert trajectories to *puts*, and insert all *puts* into HBase table regions. When executing the *quering*, we first extract the DP features of a given trajectory. Then, we push down global pruning (*G-Pruning*) and local filtering (*L-Filtering*) into the coprocessor of HBase.

The *storing* component includes *calculating* XZ* index value, *extracting* DP-features, and *building pu*. Firstly, trajectories are indexed using appropriate index space and encoded using XZ* index value (cf. Section 4). Then, we use Douglas-Peucker (DP) algorithm to pre-calculate DP features of the trajectory to speed up query processing. After that, to convert the trajectory as a *put* of HBase, *TraSS* combines the index value and the id of the trajectory as the *rowkey* and records the other information (e.g., DP-features) as columns. Then all *puts* are inserted into HBase table regions. The *rowkey* of *TraSS* for storing is combined as follows,

$$rowkey = shards + index\ value + tid,$$

where *shards* is a hash number to decentralize trajectories, which can avoid data skew problem; *indexvalue* represents the spatial information of the trajectory; *tid* is the identifier of the trajectory.

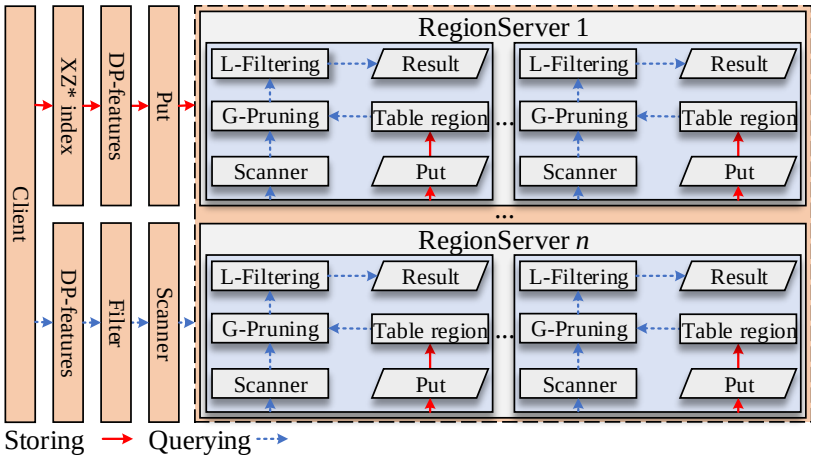


Figure 3: Architecture of *TraSS*.