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Karlsruher Institut für Technologie

Flexible User-Friendly Trip Planning Queries

Bachelorarbeit
von

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an der Fakultät für Informatik

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Bearbeitungszeit: 01. November 2018 – 14. April 2019

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Karlsruhe, den 12. März 2019

Abstract

Trip planning queries are often from the type Sequenced route Queries (SRQ), a form of nearest neighbor queries, which define a starting point and a list of categories, given by the user. This type of queries are gaining significant interest, because of advances in location based mobile services and they are also of great importance in developing robust systems, where crisis management is of utter importance.

Existing approaches strive to find a best route, based on length, duration or other prime factors, passing through multiple location, called points of interest (PoIs), and they match the route perfectly. However, users may be also interested in other qualities of the route, such as the relationship among sequence points, hierarchy, order and priority of the PoIs. Therefore, in this thesis I introduce a set of operators, which the users may be interested in applying to SRQ, and propose approaches to designing and implementing some of the operators. The implementation considers metric spaces, as these are mostly relevant to the user, when working with road networks in real-life maps.

main conclusion

Contents

Chapter 1

Introduction

1.1 Motivation

A sequenced route query is defined as finding the shortest path from a starting point towards a possible destination, passing through multiple locations, defined by their category type. There has been significant research and proposed approaches on the topic, but there is not a developed query language to answer this types of queries. The work in this thesis has been focused on researching the topic of sequenced route queries and designing a language to enable the user to express his need in the form of a user query in a flexible manner, such as applying different constraints on the route to be found.

Example: Suppose that a user is planning a trip to town: he first wants to go to a restaurant for lunch, then he wants to stop by a bank, then he meets a friend in the shopping mall and after that he plans to have a dinner at a restaurant. In this specific scenario, the user wants to express his wish for the restaurant to be the same, because he may prefer a route where the equality of the two restaurant PoIs is more important to him than the length of the route.

With existing approaches, the user may get the shortest route [5] or all routes that satisfy the semantic similarity and length conditions equally [6], but that does not guarantee the equality of the two restaurant PoIs. Also finding k optimal routes answering the user's SRQ and then filtering out the routes where the two PoIs of type restaurant are equal has proven to not always generate a result, which is why in this thesis an optimal approach is presented.

Specific constrains such as the equality in the given example above are proposed in the thesis as operators on the query. Existing approaches have been used to transform the complex user query and changes to the approaches have been made in order to retrieve a desired result.

1.2 Problem definition

We have a starting point sp and a category sequence $M = (c_1, c_2, ..., c_n)$, which constitutes the query, defined by the user. The constraints for this query can be applied as operators. For this query a route $(r_1, r_2, ..., r_n)$, defined as a sequence of PoIs, is calculated.

Graph model: The graph is constructed using Berlin's spatial datasets from [1], structured in separate CSV files for the crossroads, roads and points of interest. For the implementation of the operators the datasets are imported into a graph structure of nodes and edges, where each node has a unique id, its latitude and longitude and a list of PoIs that have been mapped to it and each edge has a source and destination node and the distance between the two nodes in kilometers as parameters. Each PoI is mapped to the nearest crossroad and has a unique id, a type, its latitude and longitude and the distance to the node it is mapped to.

The map used for implementation and testing is the road network of Berlin, with 428769 crossroads, 504229 roads, 5548 PoIs and 7 category types: restaurant (2081), coffee shop (1002), atms/banks (597), movie theaters (141), pharmacies (589), pubs/bars (958), gas stations (180).

1.3 Challenges

Challenges

1.4 Contributions

Contributions

The remainder of the thesis is organized as follows: First I review the related work that has been done on the topic of SRQ in Section 2. In Section 3 I cover the proposed operators and go into details on some of them in three separate sections for each of them: Design, Implementation and Evaluation. Finally, I conclude the thesis by summing up the progress made on the subject and discuss future work.

1.4.1   Notations and Preliminaries

Chapter 2

Related Work

In this section I would like to review some existing research, related to the topic of this thesis. Sequenced route queries have been extensively researched and different algorithms that optimize the problem and address different use scenarios have been developed. Usually, existing approaches differentiate between vector and metric spaces, considering the Euclidean distance between geographic points or the real-life road-network-based distances accordingly. Some algorithms are focused on returning a single optimal route, where the PoIs match the given categories in the category sequence perfectly, whereas others consider semantic hierarchy or multiple route factors such as rating, distance and category weights.

In *The Optimal Sequenced Route* the researchers propose two effective algorithms for solving the sequenced route query problem. They first elaborate on why a classic shortest path algorithm such as Dijkstra would be impractical for real-life scenarios and then go on to propose the LORD (Light Optimal Route Discoverer) and R-LORD algorithm, which uses a R-tree, which are Dijkstra-based and made for vector spaces and the PNE (Progressive Neighbor Exploration) algorithm, which emplys the nearest neighbour search and is designed specifically for metric spaces. Both of their proposed algorithms calculate a perfect route and only return one optimal route (while modification of the PNE algorithm also allow for finding k optimal routes), significantly outperforming Dijkstra's algorithm. [5]

A different approach to the SRQ, designed for metric spaces, is proposed in *Sequenced Route Query with Semantic Hierarchy*. The authors suggest a Skyline based algorithm, called bulk SkySR (BSSR), which searches for all preferred routes to users by extending the shortest route search with the semantic similarity of PoIs' categories. This approach expects a category tree, representing the semantic hierarchy of categories, and applies the Skyline concept, which is searching for routes that are not worse than any other routes in terms of their

5

scores, to the route length and semantic similarity, also known as the route scores. The BSSR algorithm also exploits the branch-and-bound concept by searching for routes simultaneously to reduce the search space. [6]

Another research article proposes the Personalized and Sequenced Route (PSR) Query, which considers both personalization and sequenced constraints. The approach takes into account multiple factors of a route, such as distance rating and associates different weight with each PoI category and a distance weight. The framework designed to obtain one optimal route consists of three phases: guessing, crossover and refinement, and is focused on spatial databases. [3]

In *In-Route Skyline Querying for Location-Based Services* queries are issued by user moving along a routes towards destinations (PoIs), also defined as query points. The movement of the user is constrained to a road network and the travel distance is considered. In-route queries know the destination and current location of the user, which dynamically changes, and the anticipated route towards the endpoint. Users can apply weights to several spatially-related criteria, when deciding on PoIs to visit next, such as the total distance difference, known as detour, and the relative distance of the current data point. [4]

An article *Sequenced Route Queries: Getting Things Done on the Way Back Home* suggest speedup techniques for sequenced route queries. A contraction hierarchy is proposed for preprocessing results for faster retrieval of answers by shortest path queries in road networks. The second technique uses the distance sensitivity of routes ("most queries are of a local kind"), which it bases on users' typical behavior. In this approach, one optimal route is returned, but queries where the order of PoIs is not necessarily fixed are possible as long as the number of PoIs remains moderate. Also, constraints on the order of visited PoIs can be made, e.g. visiting a restaurant before a shopping center. [2]

Chapter 3

Operators

In this chapter the proposed operators are covered in terms of their design, implementation and evaluation.

Necessity: some of the PoIs in the route can be missing
Conjunction, disjunction and negation: applied to some of the user-specified categories in the sequence
Order: some of the PoIs in the route must be in the given order
Hops between PoIs: defined number of PoIs between the given categories
Perfection: some of the PoIs in the route must match the user-specified category perfectly

3.1 Equality operator

The equality operator is based on the need to express that some PoIs in the SRQ of the same category can or should be equal, as given in the example in Chapter 1 1

3.1.1 Problem definition

3.1.2 Precomputations

3.1.3 Proposed approach

The equality operator is designed using the PNE approach, proposed in [5]. It uses the progressive neighbour explorator as its base to upgrade on and extends it with a heuristic approach to shrink the search space.

For generating the routes and deciding which of them are worth further expanding on, the proposed approach uses an initially calculated upper bound of an artificially build OSR, which satisfies the equality condition, and compares it to a lower bound of a route, considered by the algorithm. The lower bound of a certain route represents the sum of its length and the maximum distance from the distances to PoIs from the set of categories that are yet to be expanded. This is the heuristic of a route. 9

Algorithm

First, an optimal sequenced route is found using the PNE algorithm 8. It is checked, if the two PoIs that the user has asked to be equal, are equal in the OSR. If so, the OSR is returned, else the equality operator continues with the modified PNE algorithm.

Second, we artificially create a sequenced route from the optimal route, found by PNE, as seen in 2. The optimal route is changed, so that r_j is made to be equal to r_i and the length of the artificially created PSR is the initial upper bound, by which later partial sequenced routes are either kept or discarded. The $firstPSR$ is a partial SR, which contains all the PoIs from the optimal route, found by PNE, until r_i, and it is kept and build upon.

The modified PNE algorithm 3 begins iterating all r_i from the category set U_{M_i}, which are subsequent to r_{i-1} in the $firstPSR$ and it compares the lower bound, generated by them, to the global upper bound. They are only considered in further steps of the algorithm, if the partial sequenced route has a smaller lower bound than the upper bound.

Next, the modified PNE algorithm acts as a PNE algorithm and it fetches partial sequenced routes from the heap and generates new routes. There are four distinct cases depending on the length of the route and whether c_j is to be further expanded. Case one 4 and four 7 follow the original PNE. Case two 5 is focused on finding the travel distance between r_{j-1} and r_i.

Algorithm 1: equalityOperator

Input : $Query(sp, M = (c_1, c_2, ..., c_n)), Equal(i, j)$
Output: $Route = (r_1, r_2, ..., r_n)$

1 *initialize heap*;
2 *initialize UB*;
3 *optimalRoute* =PNE(*Query*);
4 **if** *optimalRoute*[i] = *optimalRoute*[j] **then**
5   optimal route has been found;
6   **return** *optimalRoute*;
7 **else**
8   dummySR();
9   modifiedPNE();
10 **end**

Procedure dummySR(*optimalRoute*)

1 $firstPSR \leftarrow (r_1, r_2, ..., r_{i-1})$;
2 // Creating a dummy SR (partial sequence route) from the found optimal route; replacing r_j with r_i
3 $dummySR = (r_1, r_2, ..., r_{i-1}, r_i, ..., r_i)$; // First part of the route
4 $dummySR \leftarrow add$ PNE($r_i, (c_{j+1}, ..., c_n)$);
5 $UB =$ length($dummySR$);
6 place $dummySR$ on the *heap*;

Correctness

3.1.4 Experimental study

Algorithm 2: `modifiedPNE` returns Route

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1 **foreach** r_i *in* U_{M_i} **do** Checking the upper bound for every r_i neighbor of
    r_{i-1} in the category set U_{M_i}
2   build a new PSR by adding r_i to $firstPSR$;
3 $LB = $ `length(`PSR`)` $+$ `max(`r_i`)`;
4   **if** $LB <= UB$ **then**
5   place the new PSR $(r_1, ..., r_{i-1}, r_i)$ on the $heap$;
6   **end**
7 **end**
8 fetch a PSR from the $heap$;
9 **switch** $l = size(PSR)$ **do**
10   **case** $l <= j - 1$ **do** Finding PSRs before r_j
11   `case1();`
12   **end**
13   **case** $l = j$ **do** Finding PSR containing r_j
14   `case2();`
15   **end**
16   **case** $l = j + 1$ **do** Finding PSR after/containing r_j
17   `case3();`
18   **end**
19   **case** $l >= j + 2$ **do** Finding PSRs after r_j
20   `case4();`
21   **end**
22   **case** $l = m$ **do** Optimal route with equal PoIs at i and j has been
         found
23   **return** SR;
24   **end**
25 **end**

Procedure caseOne

---

1 a) `nearestNeigbour(`$r_k, U_{M_{k+1}}$`);`
2 update PSR to contain r_{k+1};
3 $LB = $ `length(`PSR`)` $+ $ `max(`r_{k+1}`);`
4 **if** $LB <= UB$ **then**
5 $\quad$ place PSR on the *heap*;
6 **else**
7 $\quad$ **break**;
8 **end**
9 b) `kNearestNeigbour(`r_{k-1}, U_{M_k}`);`
10 update PSR;
11 $LB = $ `length(`PSR`)` $+ $ `max(`r_k`);`
12 **if** $LB <= UB$ **then**
13 $\quad$ place PSR on the *heap*;
14 **else**
15 $\quad$ **break**;
16 **end**

Procedure caseTwo

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1 a) `travelDistance(`(r_{j-1}, r_i)`);`
2 update PSR to contain r_i in the place j;
3 $LB = $ `length(`PSR`)` $+ $ `max(`r_j`);`
4 **if** $LB <= UB$ **then**
5 $\quad$ place PSR on the *heap*;
6 **else**
7 $\quad$ **break**;
8 **end**
9 b) `kNearestNeigbour(`$r_{j-2}, U_{M_{j-1}}$`);`
10 update PSR;
11 $LB = $ `length(`PSR`)` $+ $ `max(`r_{j-1}`);`
12 **if** $LB <= UB$ **then**
13 $\quad$ place PSR on the *heap*;
14 **else**
15 $\quad$ **break**;
16 **end**

Procedure caseThree

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1 a) `nearestNeigbour`$(r_j, U_{M_{j+1}})$;
2 update PSR to contain r_{j+1};
3 $LB = $ `length`$(PSR) + $ `max`(r_{j+1});
4 **if** $LB < UB$ **then**
5 $\quad\mid\quad$ place PSR on the *heap*;
6 **else**
7 $\quad\mid\quad$ **break**;
8 **end**
9 b) `// Found in caseTwo`

Procedure caseFour

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1 `// Same procedure as caseOne() + trimming part to`
`    filter SR and update UB if needed`
2 a) `nearestNeigbour`$(r_k, U_{M_{k+1}})$;
3 update PSR to contain r_{k+1};
4 $LB = $ `length`$(PSR) + $ `max`(r_{k+1});
5 **if** $LB <= UB$ **then**
6 $\quad\mid\quad$ `// Trimming part`
7 $\quad\mid\quad$ `trim`(PSR);
8 **else**
9 $\quad\mid\quad$ **break**;
10 **end**
11 b) `kNearestNeigbour`(r_{k-1}, U_{M_k});
12 update PSR;
13 $LB = $ `length`$(PSR) + $ `max`(r_k);
14 **if** $LB <= UB$ **then**
15 $\quad\mid\quad$ `// Trimming part`
16 $\quad\mid\quad$ `trim`(PSR);
17 **else**
18 $\quad\mid\quad$ **break**;
19 **end**

Algorithm 3: PNE

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1 `// Incrementally create the set of candidate` `routes for` $Query(sp, M)$ `from starting point` sp `towards PoI set` U_{M_m}

2 `// Candidate routes are stored in a heap sorted` `by length of the routes`

3 `// At each iteration of PNE a` PSR `(partial` `sequenced route) is fetched and examined based` `on its length`

4 `// Trimming:  There must be only one candidate SR` `on the heap`

5 **switch** $l = length(PSR)$ **do**

6   **case** $l = m$ **do**

7 | PSR is the optimal route;

8   **end**

9   **case** $l \neq m$ **do**

10   a) `nearestNeigbour` ($r_{|PSR|}, U_{m_{|PSR|+1}}$);

11   update PSR and put it back on the *heap*;

12   b) `kNearestNeigbour` ($r_{|PSR|-1}, U_{m_{|PSR|}}$);

13   generate a new PSR and place it on the *heap*;

14   **end**

15 **end**

Procedure max(r_k)

---

1 `// Calculates the heuristic for the given route`

2 **for** c_{k+1} *to* c_n **do** For all direct neighbors to r_k of every subsequent category find the maximum distance

3 | find maximum;

4 **end**

Procedure trim(PSR)

---

1 **if** $size(PSR) = m$ **then**

2 | `// Check if the length of the found SR is less` `than the one present on the heap - update` `the` UB `and place` SR `on the` *heap* `if shorter`

3 **else**

4 | place PSR on the *heap*;

5 **end**

Chapter 4

Evaluation

The completeness of the operators stems from

Chapter 5

Conclusion and Future work

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