Karlsruhe Institute of Technology

Fakultät für Informatik

Bachelor’s Thesis
Flexible User-Friendly Trip Planning Queries

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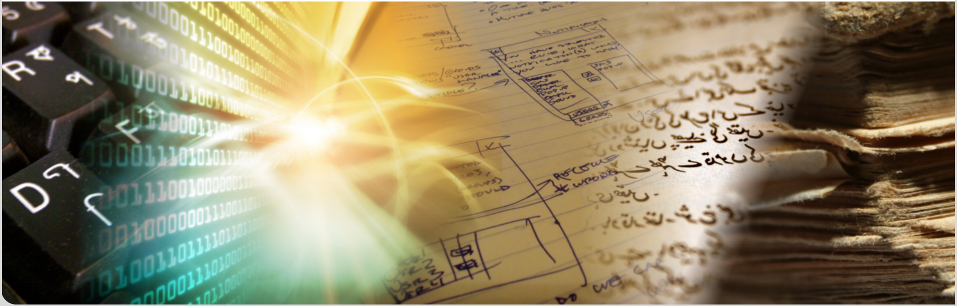

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Motivation

- *Sequenced Route Queries* (SRQ) - finding routes passing through multiple *Points of Interest* (PoIs)
- Advances in *Location Based Services* (LBS) and *Geographic Information System* (GIS) applications (e.g. logistics and supply chain management)
- Aim: Designing a language to enable the user to express his query requirements in a flexible manner

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Related work

- Vector vs. metric spaces
- *Trip Planning Queries* (TPQ)
- The *Optimal Sequenced Route* (OSR) Query
- The Skylyne concept applied to SRQ
- Considering multiple factors of a route – rating of PoIs, distance and category weights, dynamic factors (e.g. traffic information)
- SRQ issued by users moving along a route
- *Multi-rule Partial Sequenced Route* (MRPSR) Query

Example

- **Category sequence**: (restaurant, bank, movie theater, restaurant)
  Condition: equal restaurants
- *Optimal Sequenced Route* (OSR): (r_1, b_1, mt_1, r_2), length: 11 (shown with red lines)
- Optimal route with equal restaurants: (r_1, b_1, mt_1, r_1), length: 12 (shown with dashed lines)

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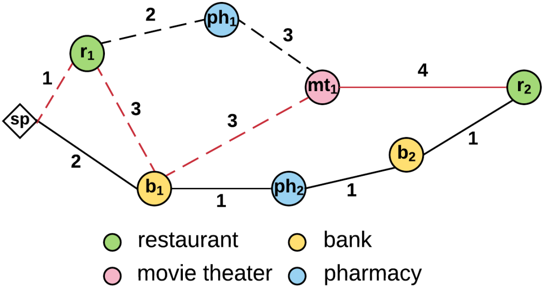

Problem definition

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- **Problem**: Need for flexibility in route finding queries
- **Solution**: Developing a query language operators to fulfill the essential user's requirements:
  - Relationships among the PoIs
  - Order and priority of the PoIs
  - Expressing multiple travel variations
- Proposing four essential operators: "equality" operator, "inequality" operator, "or" operator, "order" operator
- Making use of existing approaches (PNE (*Progressive Neighbor Exploration*)) to transform the complex user query

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PNE Algorithm

Algorithm 1: PNE

fetch a *PSR* from the heap;
switch $s = size(PSR)$ **do**
    case $s == l$ **do**
        PSR is the optimal route;
        return *PSR*;
    case $s \neq l$ **do**
        a)
            $\mathtt{NN}(r_{|PSR|}, C_{M_{|PSR|+1}})$;
            update *PSR* and perform trimming in case it is a candidate SR ;
            put *PSR* back on the *heap* ;
        b)
            $\mathtt{kNN}(r_{|PSR|-1}, C_{M_{|PSR|}})$;
            generate a new *PSR* and place it on the *heap*;

Equality operator

- *Input*: A category sequence $M = (c_1, c_2, ..., c_l)$, a starting point *sp* in $\mathbb{R}^2$ and indices of the equal PoIs i and j, where $c_i = c_j$
- *Output*: Optimal route $R = (r_1, r_2, ..., r_l)$, where $r_i = r_j$

- **Proposed approach**: uses the Progressive Neighbor Explorator (PNE) as its base to upgrade on and extends it with a heuristic approach to shrink the search space
- **Baseline/trivial approach**: extends the PNE with forcing the PoIs r_i and r_j to be equal; does not use optimization techniques

Heuristic

Given a sequence of categories $M = (c_1, c_2, ..., c_l)$ and a PSR $R' = (r_1, r_2, ..., r_k)$ the ***heuristic*** for this route is defined as:

$$h(R') = \max_{i \in [k+1, l]} nearestNeighbor(r_k, C_{M_i}) \tag{1}$$

- Informal: The heuristic of a certain PSR is the maximum distance out of the distances to the nearest PoIs from the set of categories that are yet to be expanded.

The ***lower bound*** of a PSR R' represents the sum of its length and its heuristic:

$$LB(R') = length(R') + h(R') \tag{2}$$

- The proposed algorithm uses a heap, sorted by the lower bound of the routes

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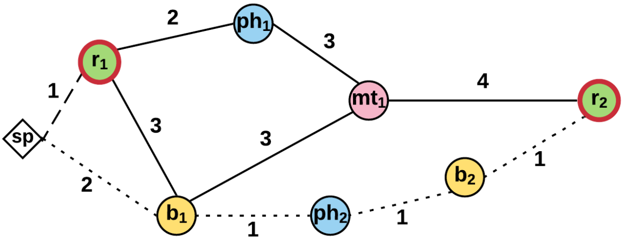
Example: Step 1

$M = (r, b, mt, r), EQUAL(0, 3)$

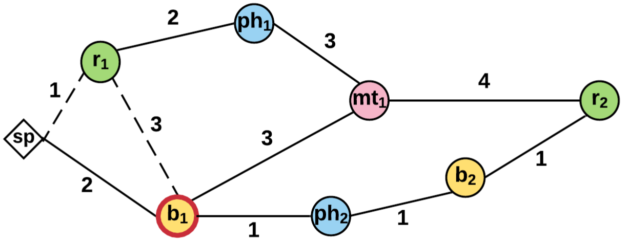
- Optimal route found with PNE: (r_1, b_1, mt_1, r_2)
- Dummy SR: (r_1, b_1, mt_1, r_1); Upper Bound $UB = length(dummySR)$



Step	Heap contents (PSR R : $length(R), heuristic(R)$)
1	$(r_1 : 1, 5), (r_2 : 5, 4)$

Example: Step 2

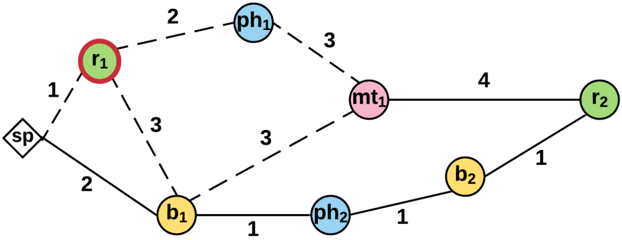
$M = (r, b, mt, r)$, $EQUAL(0, 3)$



Step	Heap contents (PSR R : $length(R)$, $heuristic(R)$)
1	$(r_1 : 1, 5)$, $(r_2 : 5, 4)$
2	$(r_1, b_1 : 4, 3)$, $(r_2 : 5, 4)$

Example: Step 8

$M = (r, b, mt, r)$, $EQUAL(0, 3)$

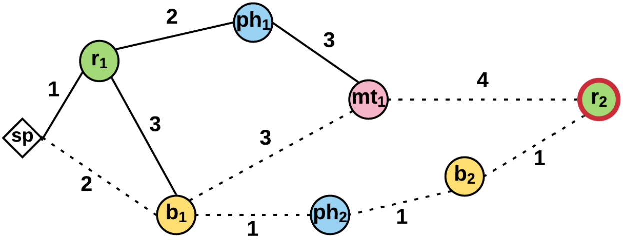


Candidate SR: $(r_1, b_1, mt_1, r_1 : 12, 0)$

Step	Heap contents (PSR R : $length(R)$, $heuristic(R)$)
7	$(r_1, b_1, mt_1 : 7, 5), (r_2, b_1, mt_1 : 11, 4), (r_2, b_2, mt_1 : 11, 4), (r_1, b_2, mt_1 : 11, 5)$
8	$(r_2, b_1, mt_1 : 11, 4), (r_2, b_2, mt_1 : 11, 4), (r_1, b_2, mt_1 : 11, 5)$

Example: Step 9

$M = (r, b, mt, r), EQUAL(0, 3)$



Candidate SR: $(r_2, b_1, mt_1, r_2 : 15, 0)$

Step	Heap contents (PSR R : $length(R)$, $heuristic(R)$)
8	$(r_2, b_1, mt_1 : 11, 4), (r_2, b_2, mt_1 : 11, 4), (r_1, b_2, mt_1 : 11, 5)$
9	$(r_2, b_2, mt_1 : 11, 4), (r_1, b_2, mt_1 : 11, 5)$

Inequality

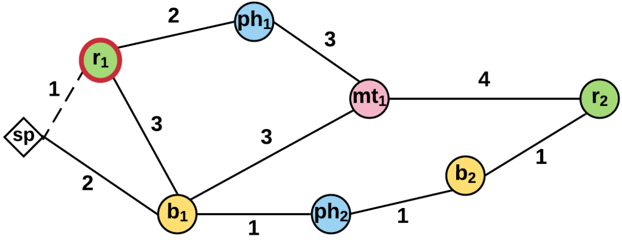
- *Input*: A category sequence $M = (c_1, c_2, ..., c_l)$, a starting point *sp* in $\mathbb{R}^2$ and indices of the unequal PoIs i and j, where $c_i = c_j$
- *Output*: Optimal route $R = (r_1, r_2, ..., r_l)$, where $r_i \neq r_j$

- **Proposed approach**: based on the Progressive Neighbor Explorator (PNE)

Example: Step 1

$M = (r, ph, r), UNEQUAL(0, 2)$

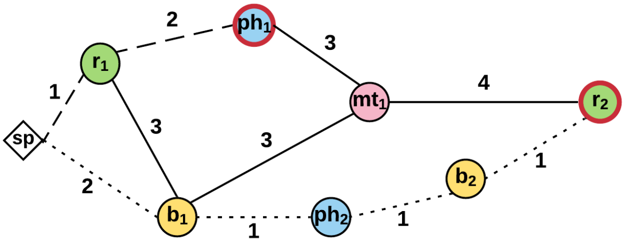
- Optimal route found with PNE: (r_1, ph_1, r_1)



Step	Heap contents (PSR R : $length(R)$)
1	$(r_1 : 1)$

Example: Step 2

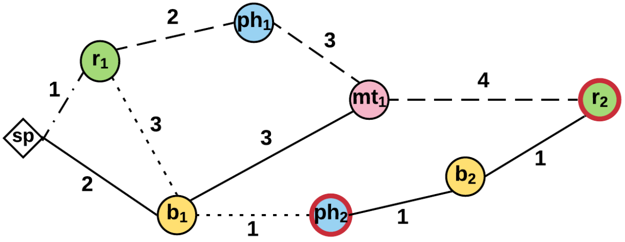
$M = (r, ph, r), UNEQUAL(0, 2)$



Step	Heap contents (PSR R : $length(R)$)
1	$(r_1 : 1)$
2	$(r_1, ph_1 : 3), (r_2 : 5)$

Example: Step 3

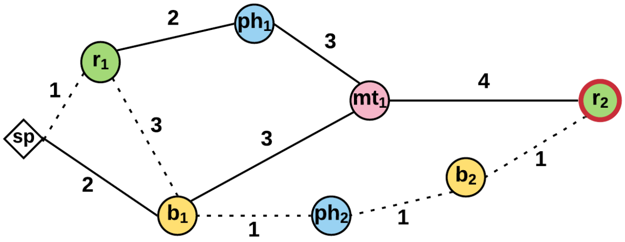
$M = (r, ph, r), UNEQUAL(0, 2)$



Step	Heap contents (PSR R : $length(R)$)
2	$(r_1, ph_1 : 3), (r_2 : 5)$
3	$(r_2 : 5), (r_1, ph_2 : 5), (r_1, ph_1, r_2 : 10)$

Example: Step 5

$M = (r, ph, r)$, $UNEQUAL(0, 2)$



Step	Heap contents (PSR R : $length(R)$)
4	$(r_1, ph_2 : 5), (r_2, ph_2 : 7), (r_1, ph_1, r_2 : 10)$
5	$(r_1, ph_2, r_2 : 7), (r_2, ph_2 : 7), \cancel{(r_1, ph_1, r_2 : 10)}$

Or

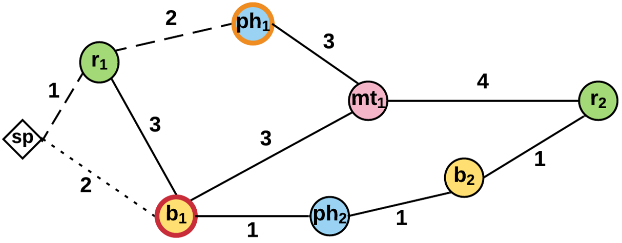
- **OR sequence:** An OR sequence $OR = (M_1, M_2, ..., M_m)$ represents the disjunction of category sequences, such as $M_1 = (c_1, c_2, ..., c_l)$.

- *Input*: A sequence of OR sequences $S = (OR_1, OR_2, ..., OR_n)$ and a starting point *sp* in $\mathbb{R}^2$
- *Output*: Optimal route $R = (r_1, r_2, ..., r_l)$

- **Proposed approach**: progressively inspects each option M_i from the OR sequences OR_i in $S = (OR_1, OR_2, ..., OR_n)$, compares them and continues with the best one, based on length, until it reaches a full sequenced route
- **Proposed approach**: runs the PNE algorithm on all possible combinations of the query to find the shortest route out of them

Example: Step 1

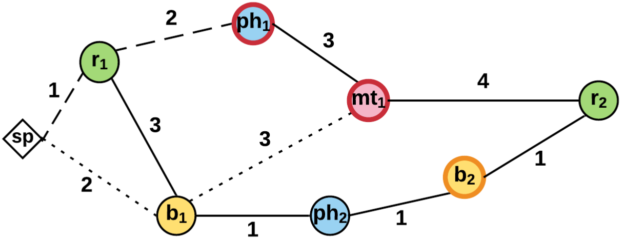
$S = (OR_1, OR_2, OR_3)$, $OR_1 = ((b), (ph))$, $OR_2 = ((mt))$, $OR_2 = ((r))$



Step	Heap contents (PSR R : $length(r)$, $index(R)$)
1	$(b_1 : 2, 1)$

Example: Step 2

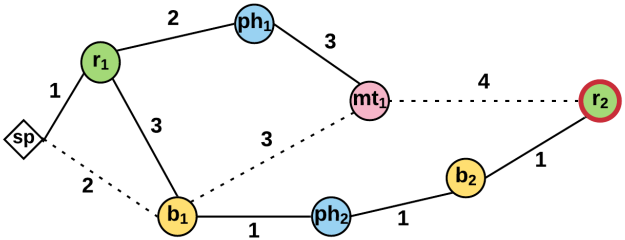
$S = (OR_1, OR_2, OR_3)$, $OR_1 = ((b), (ph))$, $OR_2 = ((mt))$, $OR_2 = ((r))$



Step	Heap contents (PSR R : $length(r)$, $index(R)$)
1	$(b_1 : 2, 1)$
2	$(ph_1 : 3, 1)$, $(b_1, mt_1 : 5, 2)$

Example: Step 6

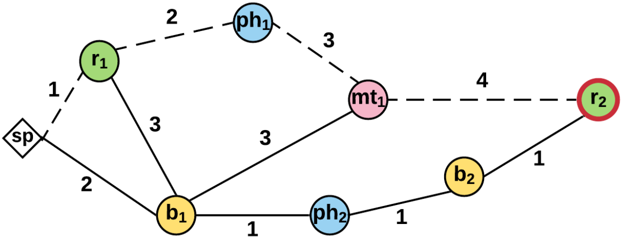
$S = (OR_1, OR_2, OR_3)$, $OR_1 = ((b), (ph))$, $OR_2 = ((mt))$, $OR_2 = ((r))$



Step	Heap contents (PSR R : $length(r), index(R)$)
5	$(b_1, mt_1 : 5, 2), (ph_1, mt_1 : 6, 2), (ph_2, mt_1 : 7, 2), (b_2, mt_1 : 9, 2)$
6	$(ph_1, mt_1 : 6, 2), (ph_2, mt_1 : 7, 2), (b_1, mt_1, r_2 : 9, 3), (b_2, mt_1 : 9, 2)$

Example: Step 7

$S = (OR_1, OR_2, OR_3)$, $OR_1 = ((b), (ph))$, $OR_2 = ((mt))$, $OR_2 = ((r))$



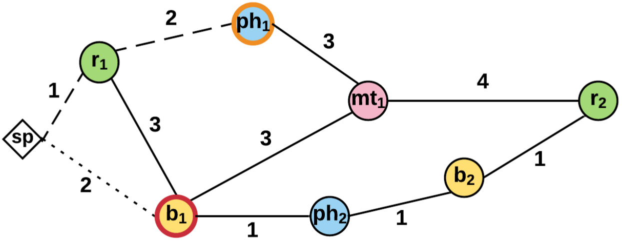
Step	Heap contents (PSR R : $length(r), index(R)$)
6	$(ph_1, mt_1 : 6, 2), (ph_2, mt_1 : 7, 2), (b_1, mt_1, r_2 : 9, 3), (b_2, mt_1 : 9, 2)$
7	$(ph_2, mt_1 : 7, 2), (b_1, mt_1, r_2 : 9, 3), (b_2, mt_1 : 9, 2)$, $\cancel{(ph_1, mt_1, r_2 : 10, 3)}$
8	$(b_1, mt_1, r_2 : 9, 3), (b_2, mt_1 : 9, 2)$, $\cancel{(ph_2, mt_1, r_2 : 11, 3)}$

Order

- **ORDER sequence:** An order sequence $ORDER = (i_1, i_2, ..., i_k)$, is a sequence of indices in a category sequence $M_1 = (c_1, c_2, ..., c_l)$, which indicate that the categories at the given indices should remain in the fixed positions in this category sequence.
- $NOTORDERED = \overline{ORDER}$
- *Input*: A sequence of categories $M = (c_1, c_2, ..., c_l)$, a starting point sp in $\mathbb{R}^2$ and an ORDER sequence $ORDER = (i_1, i_2, ..., i_k)$
- *Output*: Optimal route $R = (r_1, r_2, ..., r_l)$
- **Proposed approach**: inspects progressively each category option for the indices out of the NOTORDERED sequence, compares them and continues with the best one, based on length, until it reaches a full sequenced route.
- **Proposed approach**: runs the PNE algorithm on all possible permutations of the query to find the shortest route out of them

Example: Step 1

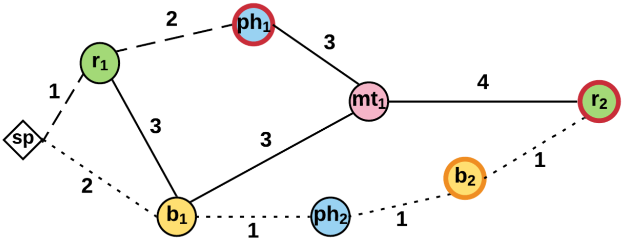
$M = (b, r, ph)$, $ORDER = (1)$



Step	Heap contents (PSR R : $length(r), r.notordered$)
1	$(b_1 : 2, [ph])$

Example: Step 1

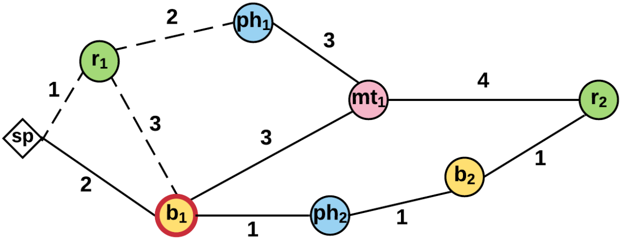
$M = (b, r, ph)$, $ORDER = (1)$



Step	Heap contents (PSR R : $length(r), r.notordered$)
1	$(b_1 : 2, [ph])$
2	$(ph_1 : 3, [b]), (b_1, r_2 : 5, [ph])$

Example: Step 6

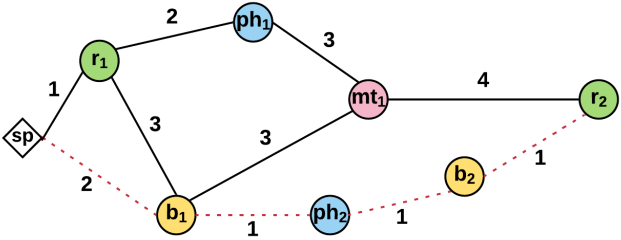
$M = (b, r, ph)$, $ORDER = (1)$



Step	Heap contents (PSR R : $length(r), r.notordered$)
5	$(ph_1, r_1 : 5, [b]), (b_2, r_2 : 5, [ph]), (ph_2, r_2 : 5, [b]), (b_1, r_2 : 5, [ph])$
6	$(b_2, r_2 : 5, [ph]), (ph_2, r_2 : 5, [b]), (b_1, r_2 : 5, [ph])$, $(ph_1, r_1, b_1 : 8, [])$

Example: Step 12

$M = (b, r, ph)$, $ORDER = (1)$



Step	Heap contents (PSR R : $length(r)$, $r.notordered$)
10	$(b_2, r_2 : 5, [ph]), (ph_2, r_2, b_2 : 6, []), \cancel{(b_1, r_1, ph_1 : 7, [])}, (ph_2, r_1 : 7, [b]), (b_2, r_1 : 9, [ph]), (ph_1, r_2 : 10, [b])$
11	$(ph_2, r_2, b_2 : 6, []), (ph_2, r_1 : 7, [b]), (b_2, r_1 : 9, [ph]), (ph_1, r_2 : 10, [b]), \cancel{(b_2, r_2, ph_1 : 12, [])}$

Example

Step	Heap contents (PSR R : $length(r), r.notordered$)
1	$(b_1 : 2, [ph])$
2	$(ph_1 : 3, [b]), (b_1, r_2 : 5, [ph])$
3	$(ph_2 : 3, [b]), (ph_1, r_1 : 5, [b]), (b_1, r_2 : 5, [ph])$
4	$(b_2 : 4, [ph]), (ph_2, r_2 : 5, [b]), (ph_1, r_1 : 5, [b]), (b_1, r_2 : 5, [ph])$
5	$(ph_1, r_1 : 5, [b]), (b_2, r_2 : 5, [ph]), (ph_2, r_2 : 5, [b]), (b_1, r_2 : 5, [ph])$
6	$(b_2, r_2 : 5, [ph]), (ph_2, r_2 : 5, [b]), (b_1, r_2 : 5, [ph]), (ph_1, r_1, b_1 : 8, [])$
7	$(b_1, r_2 : 5, [ph]), (b_2, r_2, ph : 5, [ph]), (ph_2, r_2 : 5, [b]), (b_2, r_2, ph_2 : 7, []), \cancel{(ph_1, r_1, b_1 : 8, [])}, (b_2, r_1 : 9, [ph]), (ph_1, r_2 : 10, [b])$
8	$(b_2, r_2 : 5, [ph]), (ph_2, r_2 : 5, [b]), (b_1, r_1 : 5, [ph]), (b_2, r_2, ph_2 : 7, []), \cancel{(b_1, r_2, ph_2 : 7, [])}, (b_2, r_1 : 9, [ph]), (ph_1, r_2 : 10, [b])$
9	$(b_1, r_1 : 5, [ph]), (b_2, r_2 : 5, [ph]), (ph_2, r_2, b_2 : 6, []),$ [illegible]

Equality

Inequality

Or

Order

Conclusion

Discussion and Future Work

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