Heuristic Algorithms for Bike Route Generation

Aidan Pieper
Matthew Anderson (Advisor)

Computer Science Department, Union College

March 3, 2018

- Routing for recreational cyclists is different than traditional routing problems.
- Cyclists prefer longer more scenic routes, not the shortest one.
- Our focus is on *circular* routes.

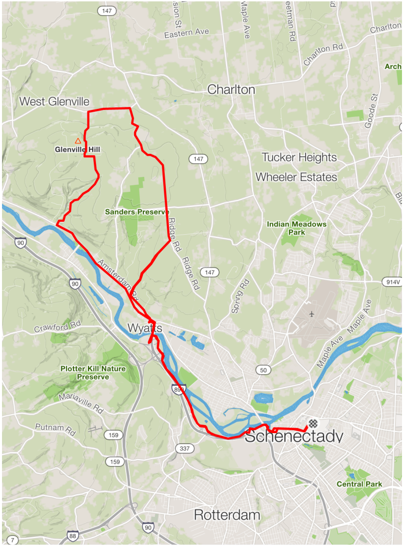


Figure 1: Circular bike route

Informal Problem Statement

Given:

- A road network
- A starting location
- A distance budget

Goal: Find the "best" bike route which starts and ends at the specified location and is no longer than the budget.

Related Work: Arc Orienteering

Previous literature [SVBVO11] [VVA14] [LS15] models this problem as an instance of the **Arc Orienteering Problem (AOP)**

- AOP is NP-Hard!

Arc Orienteering Example

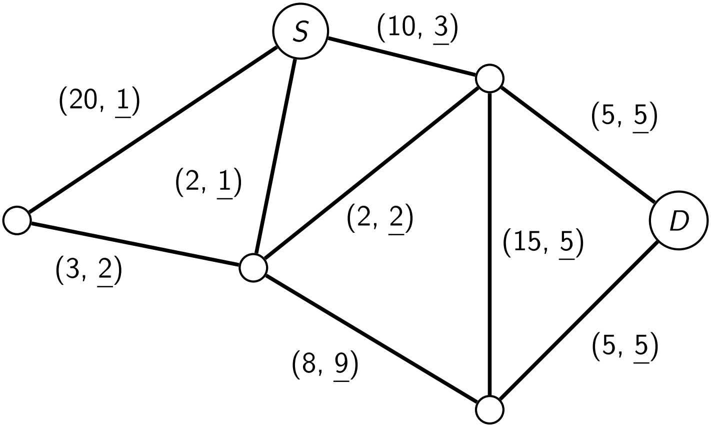


Figure 2: AOP Instance - Edge label: (*score*, *cost*) Budget: 10

Arc Orienteering Example

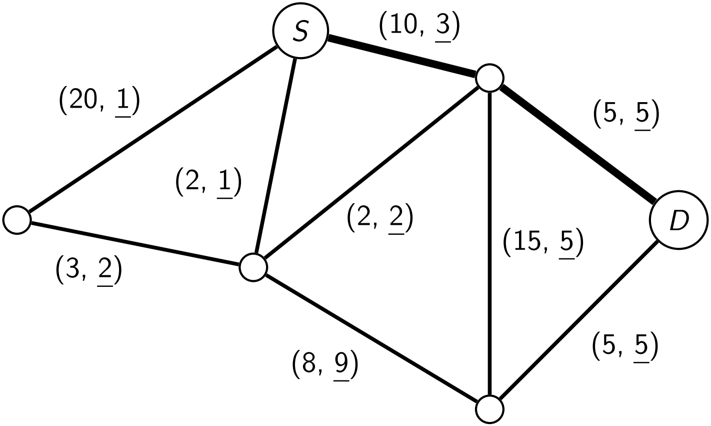


Figure 3: Shortest Path: ($score = 15$, $\underline{cost = 8}$) Budget: 10

Arc Orienteering Example

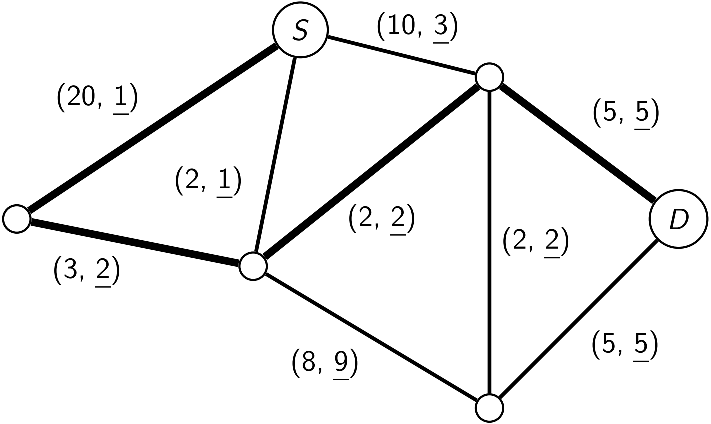


Figure 4: Optimal Path: $(\mathit{score} = 30, \underline{\mathit{cost} = 10})$ Budget: 10

Revised Problem Statement

Given:

- A graph where each arc has the following:
  - A cost (e.g. distance)
  - A score (e.g. number denoting the bike safety of the road)
- A starting and ending node
- A distance budget

Goal: Produce a *path* with specified start and end which visits some subset of the graph nodes maximizing score and is within the distance budget.

Methods

Recall that the AOP is NP-Hard:

- Our focus is on heuristic algorithms for the AOP.
- **Iterated Local Search (ILS)** is the algorithm of interest.

Research Question:

To what extent can ILS algorithms be improved to generate better bike routes?

Methods: GraphHopper Routing Engine

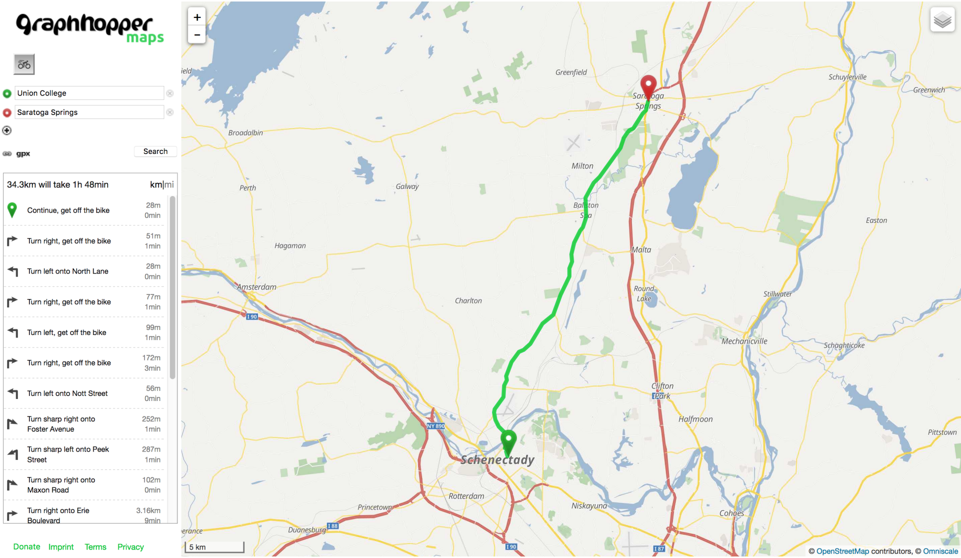
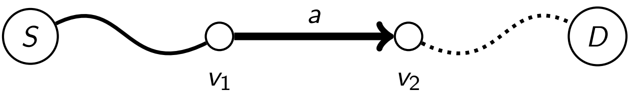


Figure 5: Shortest path Union → Saratoga Springs

Algorithm 1 [VVA14]

- Uses modified **Depth First Search** with max depth.
- Precomputes all-pairs shortest path for feasibility checking.
- Returns first path found fitting criteria.



$$(S \rightarrow v_1).cost + a.cost + ShortestPath(v_2, D) \leq Budget$$

Figure 6: Arc feasibility checking

Algorithm 1 [VVA14]

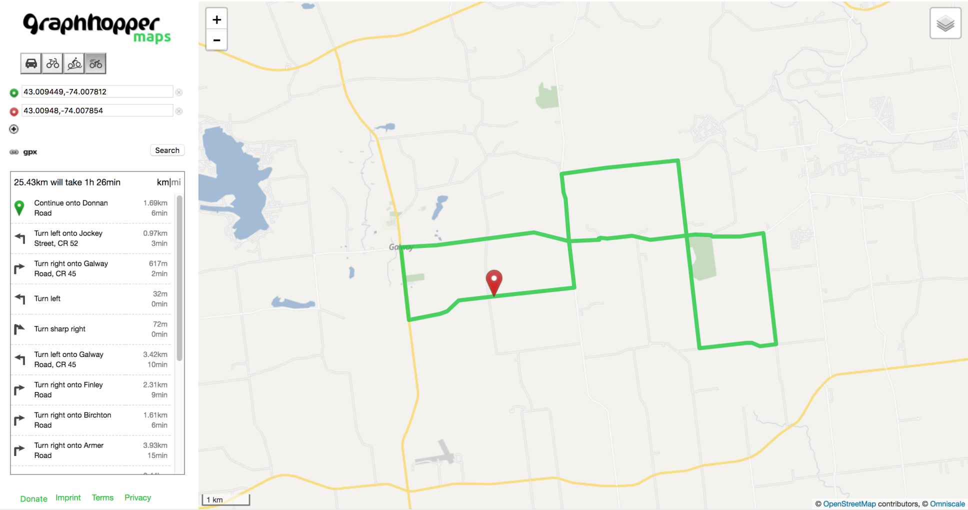


Figure 7: Algorithm 1 Example Route

Algorithm 1 [VVA14]

Limitations:

- Search space large in road dense areas.
- Requires pre-computed all-pairs shortest path.
- Does not penalize turns.

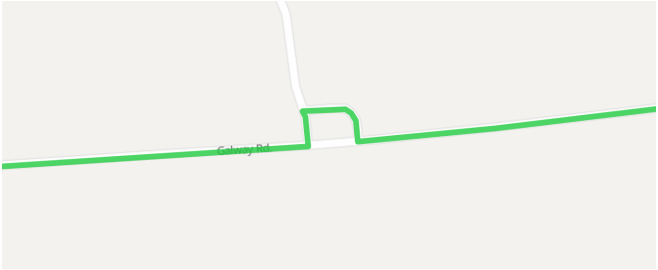


Figure 8: Dangerous route turn

Algorithm 2 [LS15]

- Generates paths by "gluing together" **Attractive Arcs** from a **Candidate Arc Set**.
- Uses spatial techniques to reduce search space.
- Uses online shortest path computations [GSSD08].

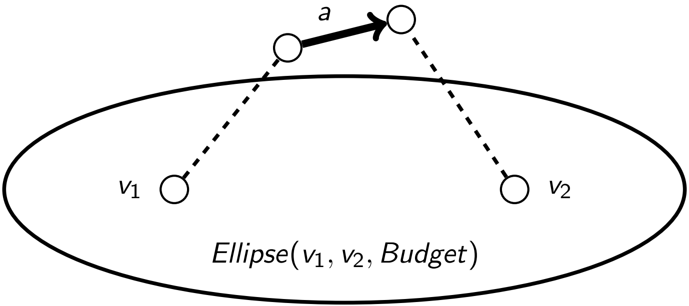


Figure 9: Ellipse pruning technique

Algorithm 2 [LS15]

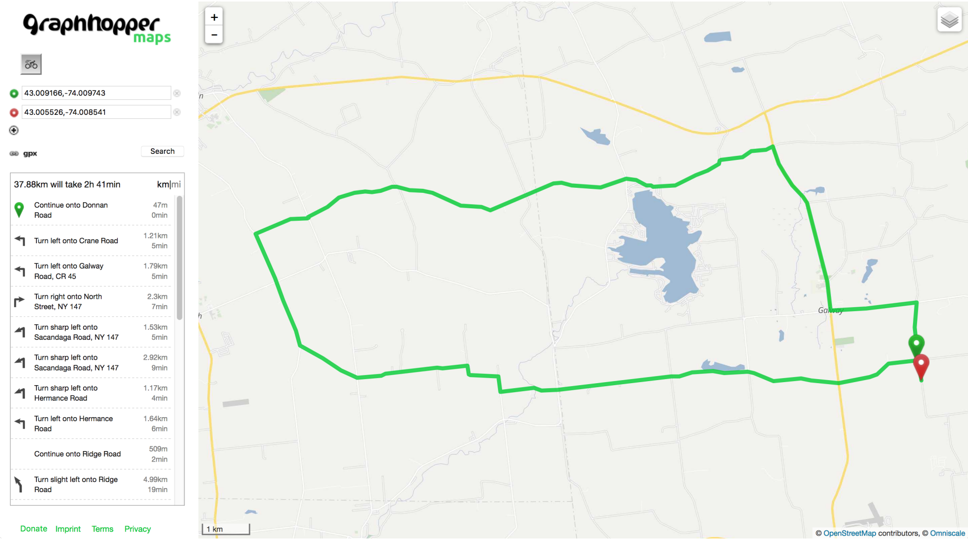


Figure 10: Perfectly circular route generated by Algorithm 2.

Algorithm 2 [LS15]

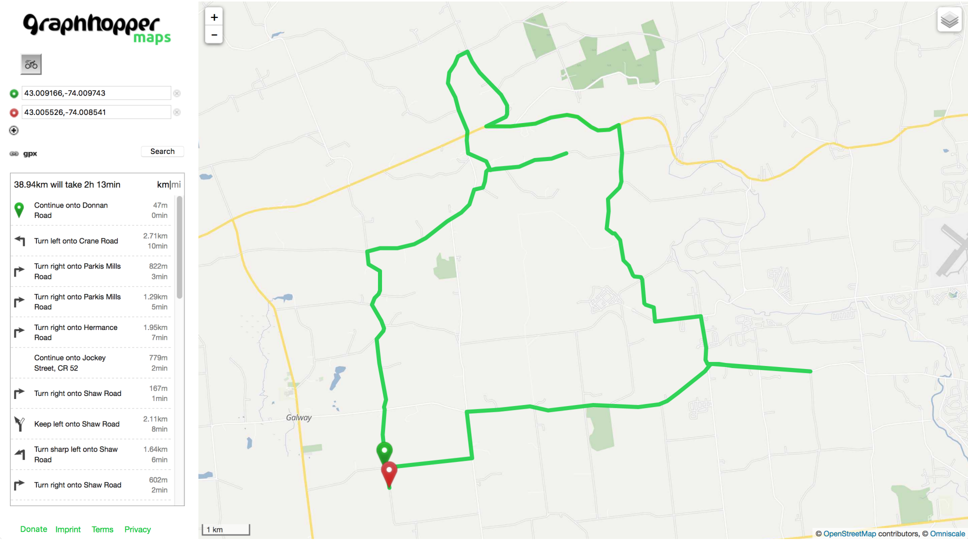


Figure 11: Route with backtracking generated by Algorithm 2.

Algorithm 2 [LS15]

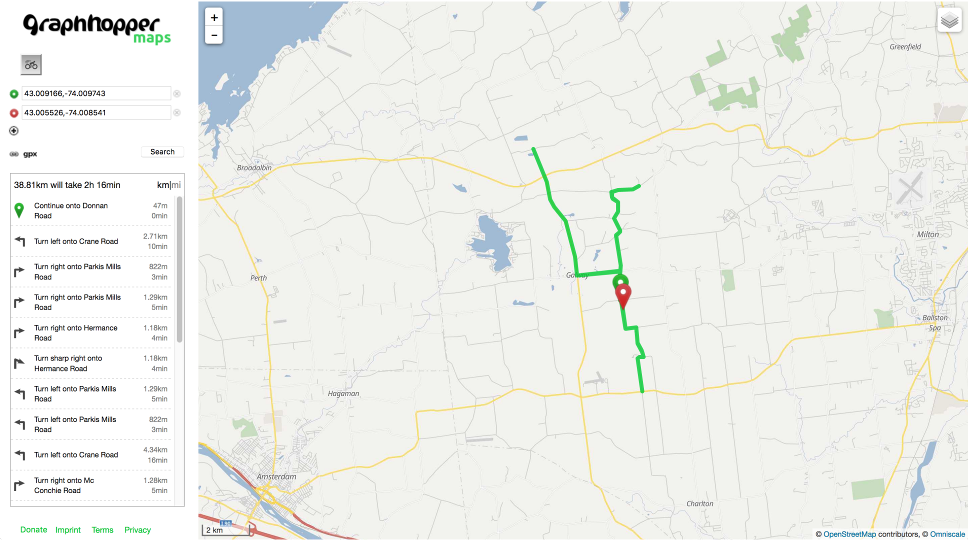


Figure 12: Route with excess backtracking generated by Algorithm 2.

Algorithm 2 [LS15]

Limitations:

- Does not avoid backtracking.
- Tries to hit budget exactly.
- Shortest path not necessarily preferable.
- Does not penalize turns.

Improvements:

- Avoid already taken roads when gluing together attractive arcs.
- Use fixed percentage of budget or incremental budget when generating paths.

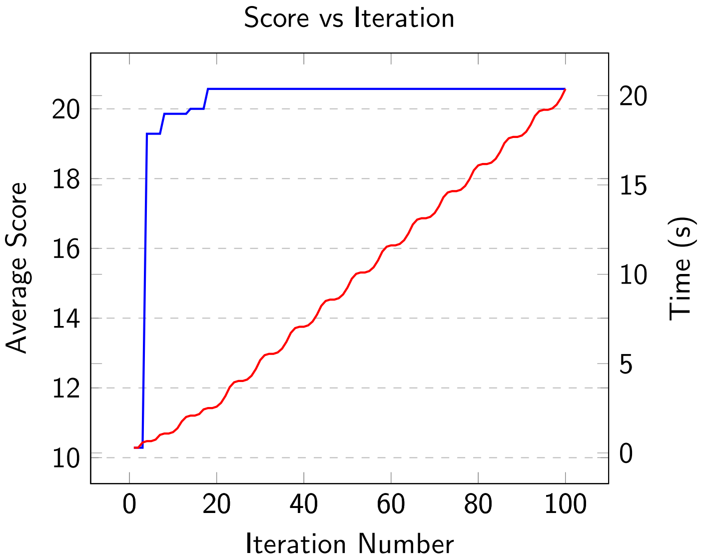


Figure 13: Route generation with Algorithm 1.

Experimental Results

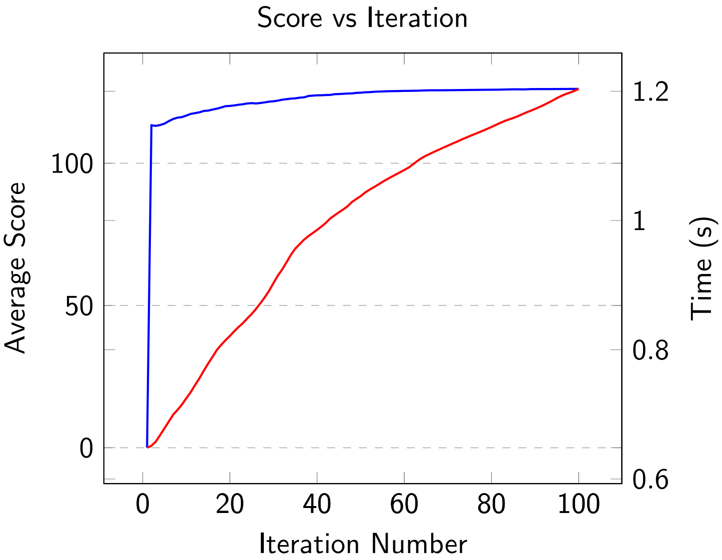


Figure 14: Route generation with Algorithm 2.

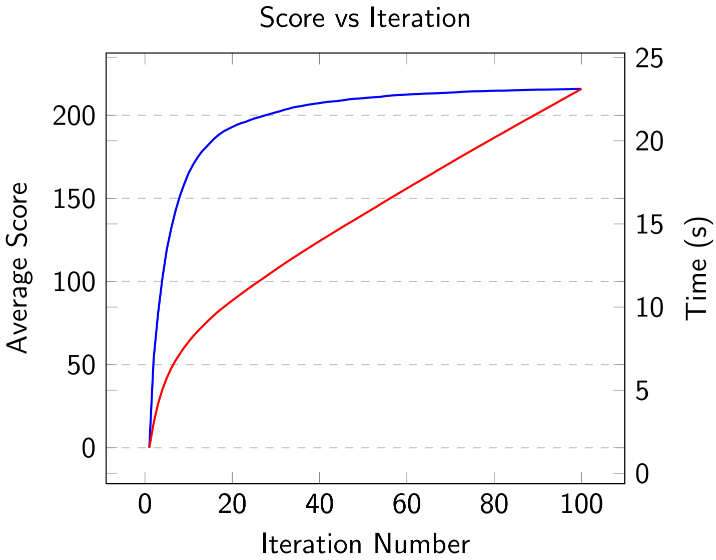


Figure 15: Algorithm 2 with 50% budget allowance.

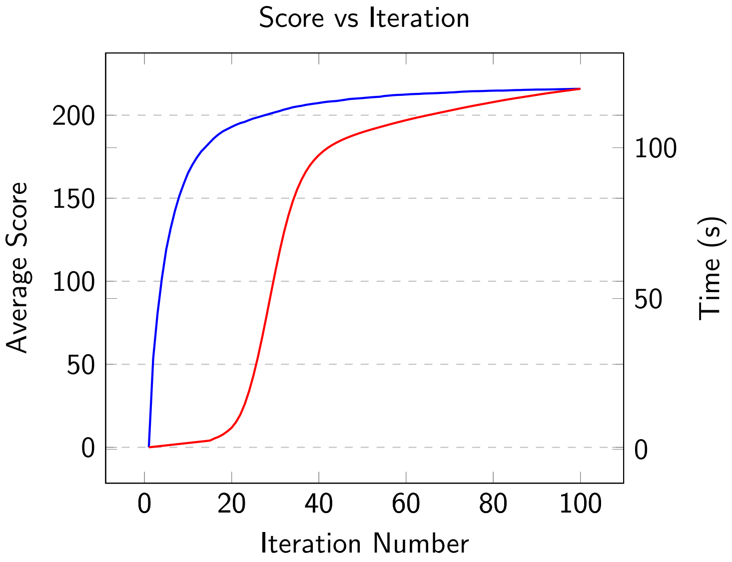


Figure 16: Algorithm 2 with incremental budget.

Experimental Results

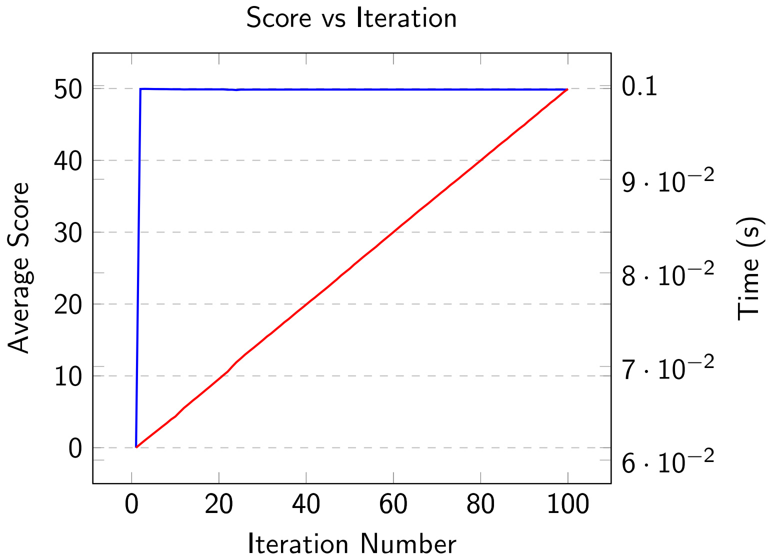


Figure 17: Algorithm 2 with attractive arc restrictions.

Integer Program Formulation [VVA14]

Given:

- An incomplete directed graph $G = (V, A)$
- A start vertex $d \in V$
- A distance budget $B \in \mathcal{R}$.

Each arc, $a \in A$ has the following:

- A cost $c_a \in \mathcal{R}$
- A profit $p_a \in \mathcal{R}$
- A complementary arc $\bar{a} \in A \cup \{\emptyset\}$

Decision variables:

- $x_a \in \{0, 1\}, \forall a \in A$
- $z_v \in \mathcal{Z}^{\geq}, \forall v \in V$

$$\textit{Objective:} \text{ Maximize} \sum_{a \in A} p_a * x_a \tag{1}$$

Integer Program Constraints

Given: $\delta(S)$ = set of outgoing arcs, $\lambda(S)$ = set of incoming arcs.

$$\sum_{a \in A} c_a * x_a \leq \mathrm{B} \tag{2}$$

$$\sum_{a \in \lambda(v)} x_a - \sum_{a \in \delta(v)} x_a = 0 \quad \forall v \in V \tag{3}$$

$$\sum_{a \in \delta(v)} x_a = z_v \quad \forall v \in V \tag{4}$$

$$\sum_{a \in \delta(S)} x_a \geq \frac{\sum_{v \in S} z_v}{\sum_{v \in S} |\delta(v)|} \quad \forall S \subseteq V \setminus \{d\} \tag{5}$$

$$z_d = 1 \tag{6}$$

$$x_a + x_{\bar{a}} \leq 1 \quad \forall a \in A : \exists \bar{a} \in A \tag{7}$$

Acknowledgements

- Major kudos to *David Frey* for helping me set up computing resources to run my experiments!

References

[GLV16] Aldy Gunawan, Hoong Chuin Lau, and Pieter Vansteenwegen. Orienteering problem: A survey of recent variants, solution approaches and applications. *European Journal of Operational Research*, 255(2):315–332, 2016.

[GP10] Michel Gendreau and Jean-Yves Potvin. *Handbook of Metaheuristics*, volume 2. Springer, 2010.

[GRA] GraphHopper Routing Engine. `https://github.com/graphhopper/graphhopper`. Visited Nov 2, 2017.

[GSSD08] Robert Geisberger, Peter Sanders, Dominik Schultes, and Daniel Delling. Contraction hierarchies: Faster and simpler hierarchical routing in road networks. *Experimental Algorithms*, pages 319–333, 2008.

[LS15] Ying Lu and Cyrus Shahabi. An arc orienteering algorithm to find the most scenic path on a large-scale road network. In *Proceedings of the 23rd SIGSPATIAL International Conference on Advances in Geographic Information Systems*, page 46. ACM, 2015.

[OSM] OpenStreetMap Wiki. `http://wiki.openstreetmap.org/wiki/Develop`. Visited Nov 13, 2017.

[SVBVO11] Wouter Souffriau, Pieter Vansteenwegen, Greet Vanden Berghe, and Dirk Van Oudheusden. The planning of cycle trips in the province of East Flanders. *Omega*, 39(2):209–213, 2011.

[VVA14] Cédric Verbeeck, Pieter Vansteenwegen, and E-H Aghezzaf. An extension of the arc orienteering problem and its application to cycle trip planning. *Transportation Research Part E: Logistics and Transportation Review*, 68:64–78, 2014.