

Heuristic Algorithms for Bike Route Generation

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Introduction

- ▶ 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.

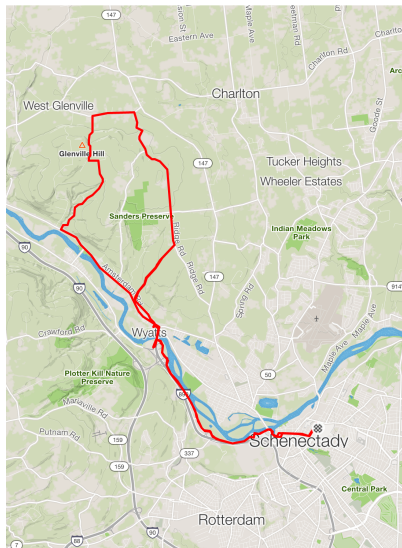


Figure 1: Circular bike route

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

Previous literature models this problem as an instance of the **Arc Orienteering Problem (AOP)**.

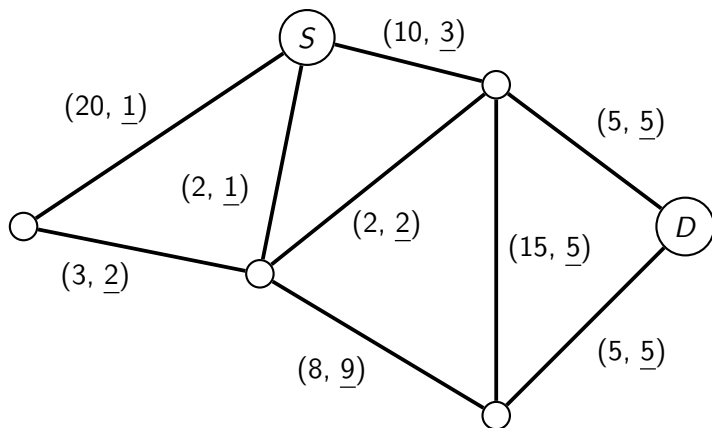


Figure 2: AOP Instance - Edge label: (score, cost) Budget: 10

Arc Orienteering Example

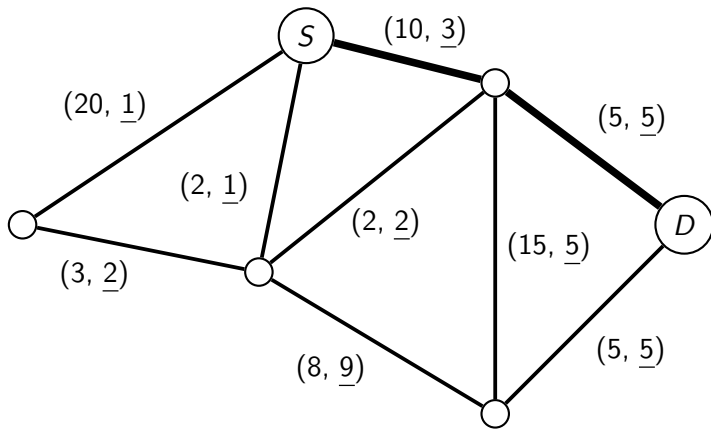


Figure 3: Shortest Path: ($score = 15$, $\underline{cost} = 8$) Budget: 10

Arc Orienteering Example

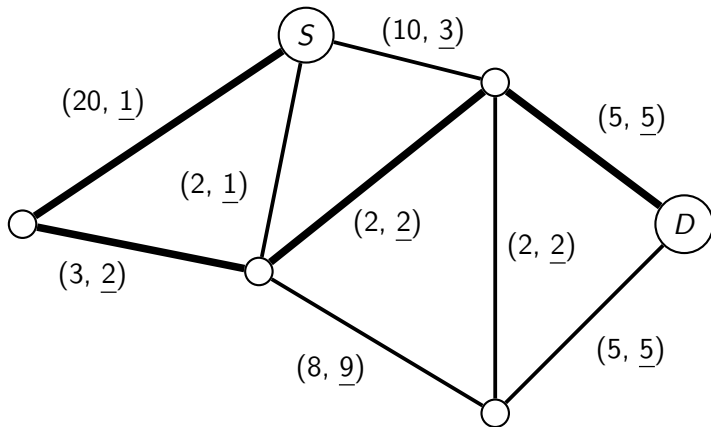


Figure 4: Optimal Path: ($score = 30$, $\underline{cost} = 10$) Budget: 10

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?

We implemented two ILS algorithms using:

- ▶ **GraphHopper**: An open source routing library.
- ▶ **OpenStreetMaps**: An open mapping dataset.

Methods: GraphHopper Routing Engine

Graphhopper
maps





34.3km will take 1h 48min km|mi

 Continue, get off the bike	28m 0min
 Turn right, get off the bike	51m 1min
 Turn left onto North Lane	28m 0min
 Turn right, get off the bike	77m 1min
 Turn left, get off the bike	99m 1min
 Turn right, get off the bike	172m 3min
 Turn left onto Nott Street	56m 0min
 Turn sharp right onto Foster Avenue	252m 1min
 Turn sharp left onto Peak Street	287m 1min
 Turn sharp right onto Maxon Road	102m 0min
 Turn right onto Erie Boulevard	3.16km 9min

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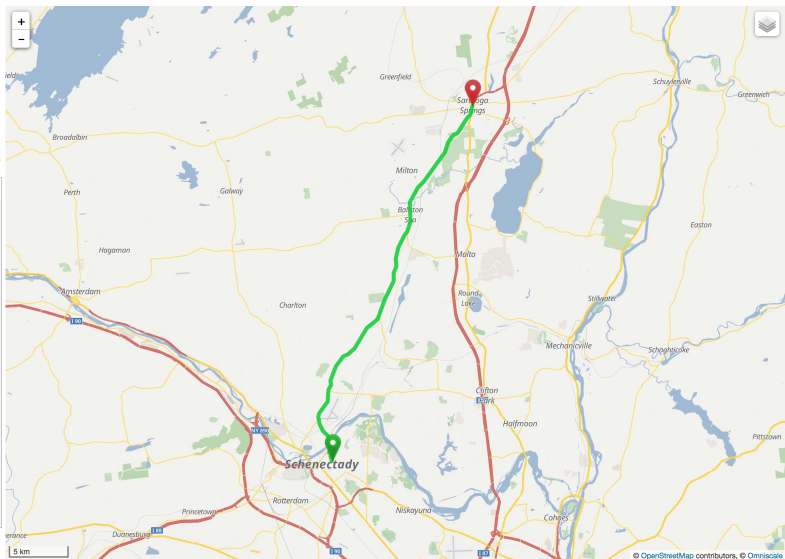
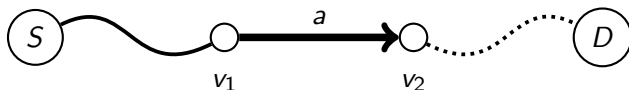


Figure 5: Shortest path Union → Saratoga Springs

- ▶ 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

DFS Algorithm [VVA14]

Graphhopper maps

🚗 🚲 🚶 🚴

📍 43.009449,-74.007812

📍 43.00948,-74.007854

🔍 Search

📄 gpx

25.43km will take 1h 26min km/mi

📍 Continue onto Donnan Road	1.69km 6min
🔄 Turn left onto Jockey Street, CR 52	0.97km 3min
🔍 Turn right onto Galway Road, CR 45	617m 2min
🔄 Turn left	32m 0min
🔍 Turn sharp right	72m 0min
🔄 Turn left onto Galway Road, CR 45	3.42km 10min
🔍 Turn right onto Finley Road	2.31km 9min
🔍 Turn right onto Birchton Road	1.61km 6min
🔍 Turn right onto Armer Road	3.93km 15min

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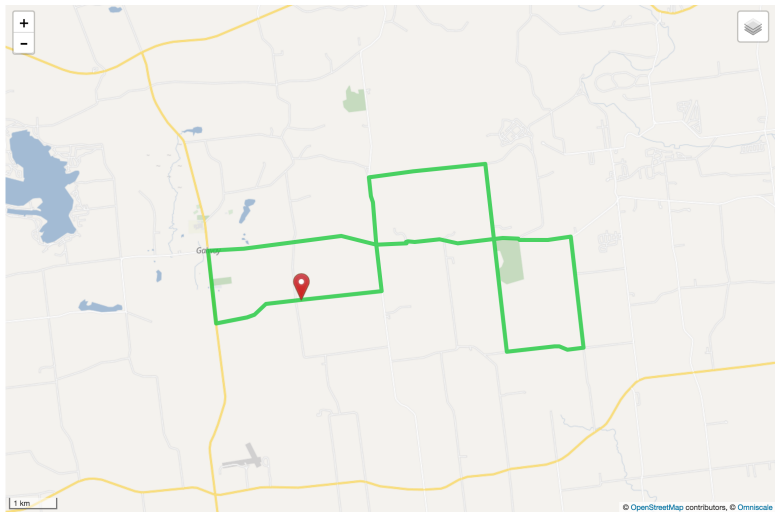


Figure 7: DFS Algorithm Example Route

DFS Algorithm [VVA14]

Limitations:

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

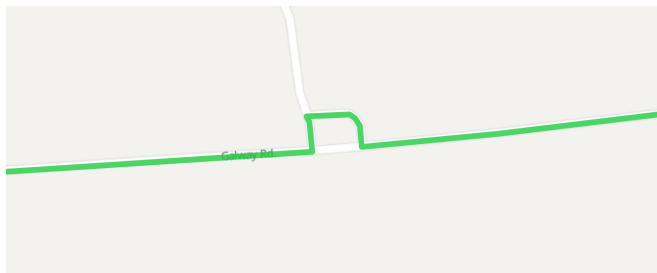


Figure 8: Dangerous route turn

Geometric Algorithm [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].

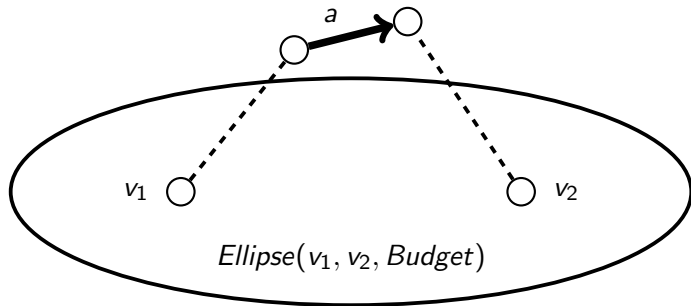


Figure 9: Ellipse pruning technique

Geometric Algorithm [LS15]

Graphhopper
maps

 43.009166,-74.009743
43.005526,-74.008541

  Search

37.88km will take 2h 41min km|mi

	Continue onto Donnan Road	47m 0min
	Turn left onto Crane Road	1.21km 5min
	Turn left onto Galway Road, CR 45	1.79km 5min
	Turn right onto North Street, NY 147	2.3km 7min
	Turn sharp left onto Sacandaga Road, NY 147	1.53km 5min
	Turn sharp left onto Sacandaga Road, NY 147	2.92km 9min
	Turn sharp left onto Hermance Road	1.17km 4min
	Turn left onto Hermance Road	1.64km 6min
	Continue onto Ridge Road	509m 2min
	Turn slight left onto Ridge Road	4.99km 19min

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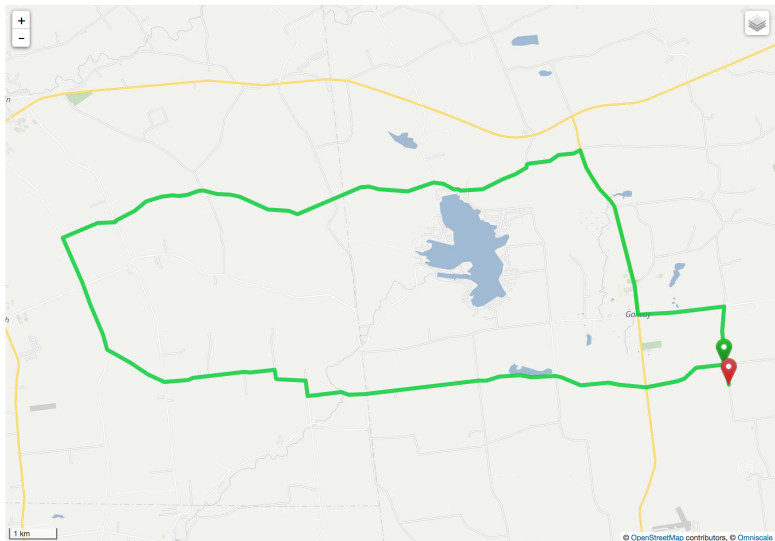


Figure 10: Perfectly circular route generated by Geometric Algorithm.

Geometric Algorithm [LS15]

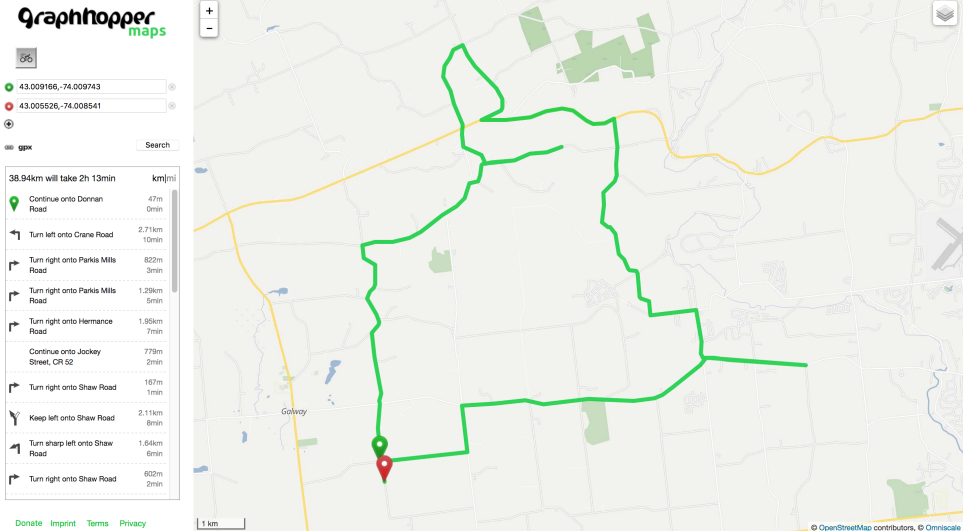


Figure 11: Route with backtracking generated by Geometric Algorithm.

Geometric Algorithm [LS15]

Graphhopper
maps





38.81km will take 2h 16min km|mi

	Continue onto Donnan Road	47m 0min
	Turn left onto Crane Road	2.71km 10min
	Turn right onto Parkis Mills Road	822m 3min
	Turn right onto Parkis Mills Road	1.29km 5min
	Turn right onto Hermance Road	1.18km 4min
	Turn sharp right onto Hermance Road	1.18km 4min
	Turn left onto Parkis Mills Road	1.29km 5min
	Turn left onto Parkis Mills Road	822m 3min
	Turn left onto Crane Road	4.34km 16min
	Turn right onto Mc Conchie Road	1.28km 5min

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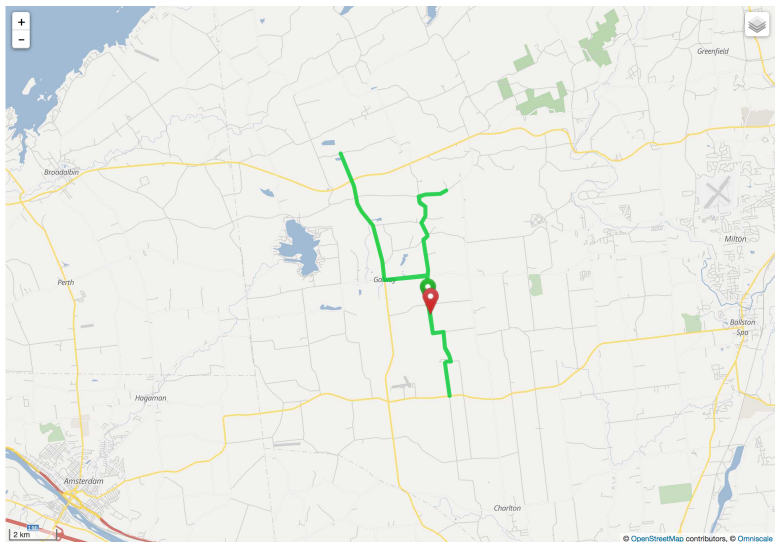


Figure 12: Route with excess backtracking by Geometric Algorithm.

Limitations:

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

We designed and implemented variants:

- ▶ Avoid backtracking when gluing together attractive arcs.
- ▶ Don't use full budget when generating paths.
- ▶ Change which attractive arcs are considered.

Results: DFS [VVA14]

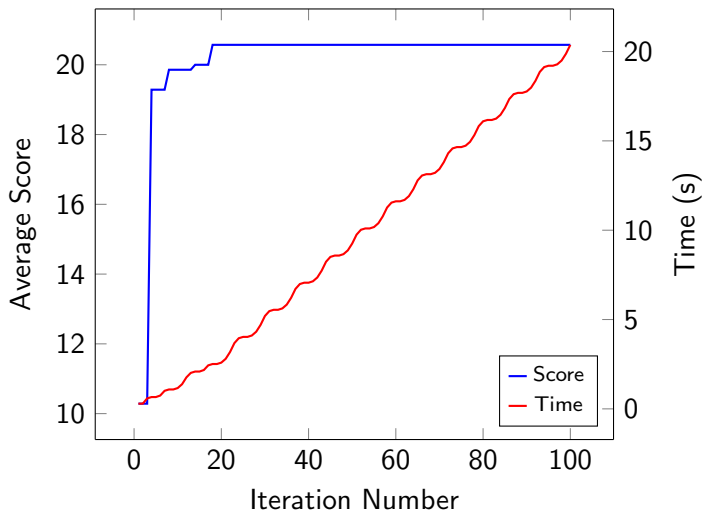


Figure 13: Route generation with DFS Algorithm.

Results: Geometric [LS15]

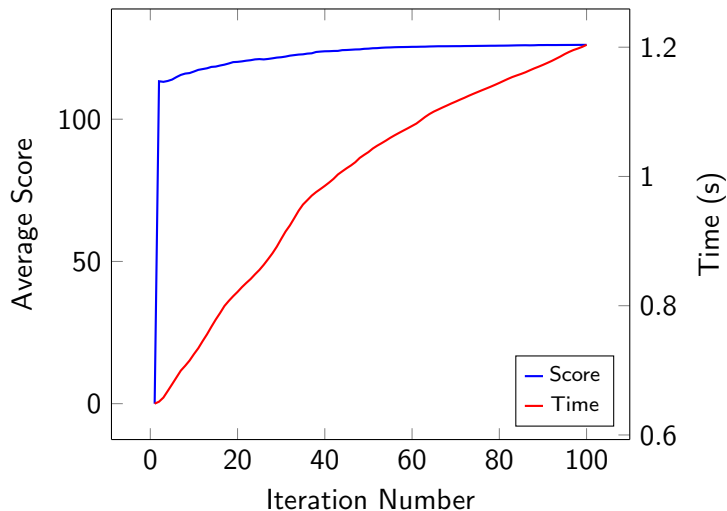


Figure 14: Route generation with Geometric Algorithm.

Results: Geometric + (Budget allowance)

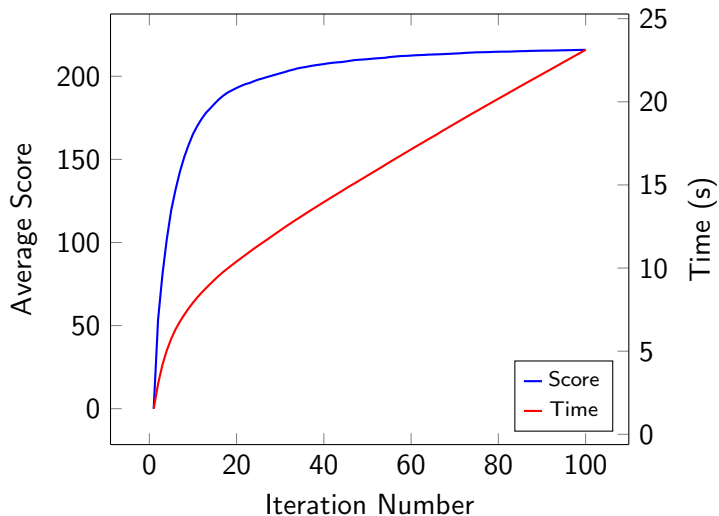


Figure 15: Geometric Algorithm with 50% budget allowance.

Conclusions

- ▶ Spatial techniques definitely speed up ILS.
- ▶ Modifying budget over time greatly increases average score at a hefty time penalty.
- ▶ Attractive arc definition and data set matter a lot in algorithm performance.

Algorithm	Score	Time (s)
DFS	20.57	20.37
Geometric	126.13	1.20
Geometric + (Budget allowance)	215.87	23.12
Geometric + (Incremental budget)	282.66	119.52
Geometric + (Arc restrictions)	49.85	0.09
Geometric + (No backtracking)	33.36	0.60

Figure 16: Algorithm performance of variants.

Acknowledgements & Comments

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

I glossed over a lot of technical details! Ask me about the following:

- ▶ Road scoring
- ▶ OpenStreetMap dataset
- ▶ Online shortest path computation (Contraction Hierarchies)
- ▶ Iterated Local Search
- ▶ Details of Algorithm 1 & 2
- ▶ Integer Programming solutions to the AOP

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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:

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

$$\text{Objective: Maximize } \sum_{a \in A} p_a * x_a \quad (1)$$

Integer Program Constraints

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

$$\sum_{a \in A} c_a * x_a \leq B \quad (2)$$

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

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

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

$$z_d = 1 \quad (6)$$

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