ECE 1724
Route Planning For Cyclists

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Problem Characterization

Problem Definition, Importance & Challenges

Problem Definition

Objective

To design and implement an algorithm to plan routes for a cyclist to meet his/her calorie goals.

Constraints

- A route's end point must be the same as the starting point.
- A route must be suited for cycling.

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Importance

- Providing a convenient way for cyclists to plan routes that are safe to ride on and meet their training goals.
- Encouraging more people to participate in physical activity.

Challenges

- Benchmarking.
- Making tradeoffs among multiple criteria when producing the fittest route.

Conditions

The following information is specified by the user before the algorithm runs:

- Starting address
- Calorie goal
    - Between 200 kcal and 4000 kcal
- Average speed
    - Between 10 mph and 20 mph
- Weight of the user (lbs)
- Weight of the bike (lbs)

Criteria

- Calculated calories spent should be as close to the user’s calorie goal as possible.
- Less traffic lights are preferred.
- Smoother (paved) road surface is preferred.

Problem Formulation and Modeling

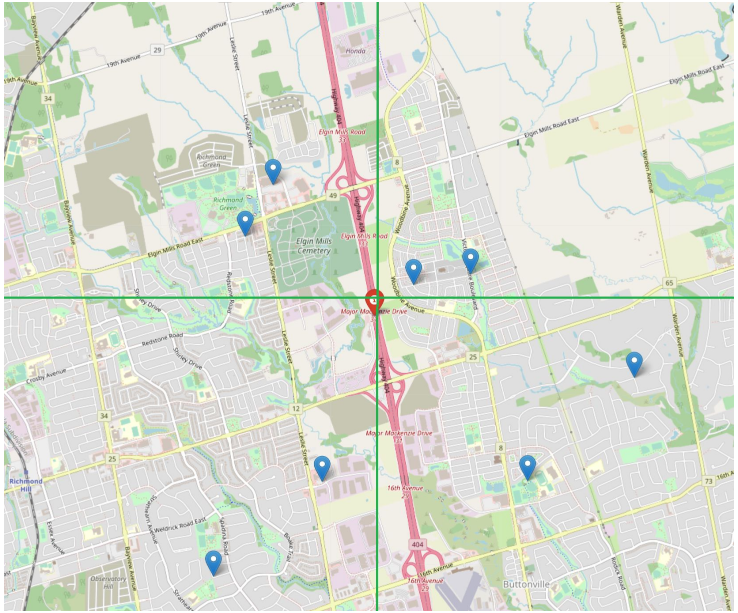
Problem Reduction

- The problem is reduced to a Travelling Salesman Problem (TSP).
- The route starts from the starting point, traverses a set of points of interest (POIs) and returns to the starting point.

POI Selection

The POIs to be traversed by the route are selected by the algorithm:

1. Calculate the dimensions of the rectangular search space based on the user's calorie goal and average speed.
2. Partition the search space evenly into 4 sections.
3. Select several POIs randomly in each section.



Offline Calculations for TSP

For each pair of points (including the starting point and all the POIs), find the route between them with minimum λ.

$$\lambda = t_{movement} + t_{delay}$$

$$t_{movement} = t_{movement-paved} + t_{movement-unpaved}$$

$$t_{delay} = 15 \times n_{light}$$

- t_movement: time of movement on the route
  - t_movement_paved: time of movement on paved road segments
  - t_movement_unpaved: time of movement on unpaved road segments

- t_delay: total waiting time at traffic lights
  - n_light: number of traffic lights on the route
  - 15: an average of 15 seconds of waiting time at a traffic light [ref]

[ref] "Traffic Signal Timing Manual," Traffic Signal Timing Manual: Chapter 5 - Office of Operations. [Online]. Available: https://ops.fhwa.dot.gov/publications/fhwahop08024/chapter5.htm. [Accessed: 27-Oct-2020].

TSP

- Design Vector X
  - x: decision variable that represents permutation of POIs

$$X = [\, x \,]^T$$

- Objective Function Ω
  - C_r: calculated calories spent after completing r
    - r: TSP route represented by decision variable x
    - c: calorie rate
    - t: total travel time of r
  - C_goal: calorie goal set by the user

$$\Omega = |\,(C_r - C_{goal})\,| \div C_{goal}$$

$$C_r = c \times t$$

- Calorie Rate c (average calories spent per hour)
  - v: average speed of the user
  - w: total weight of the user and bike
  - g: average gradient of the route

$$c = [v \times w \times (0.0053 + g) + 0.0083 \times v^3] \times 14.4$$

Summary Procedure

To solve the problem, the steps below should be performed in order:

1. Select POIs around the starting point.
2. Find the fittest route between any two points to construct a fully connected graph.
3. Find the optimum permutation of the POIs.

Proposed Solution

Proposed Solution

- Dijkstra algorithm to find the fittest route between each pair of points

- Bio-inspired algorithms to find the optimum permutation of the POIs
  - Simulated Annealing
    - At higher temperature, there is more random movement; at low temperature, there is less randomness.
    - Always accepts better steps, but accepts worse steps with some probability.
  - Particle Swarm Optimization
    - Each particle follows its own swarm leader. Swarm leaders crossover with each other.
    - Particles seek the optimal solution with both their own experience and the experience of the swarms.
  - Firefly Optimization
    - Mimicking a firefly's attraction to flashing light.
    - Luminous is equal to cost of the route plus the number of nodes.

Comparative Study

Comparative Study

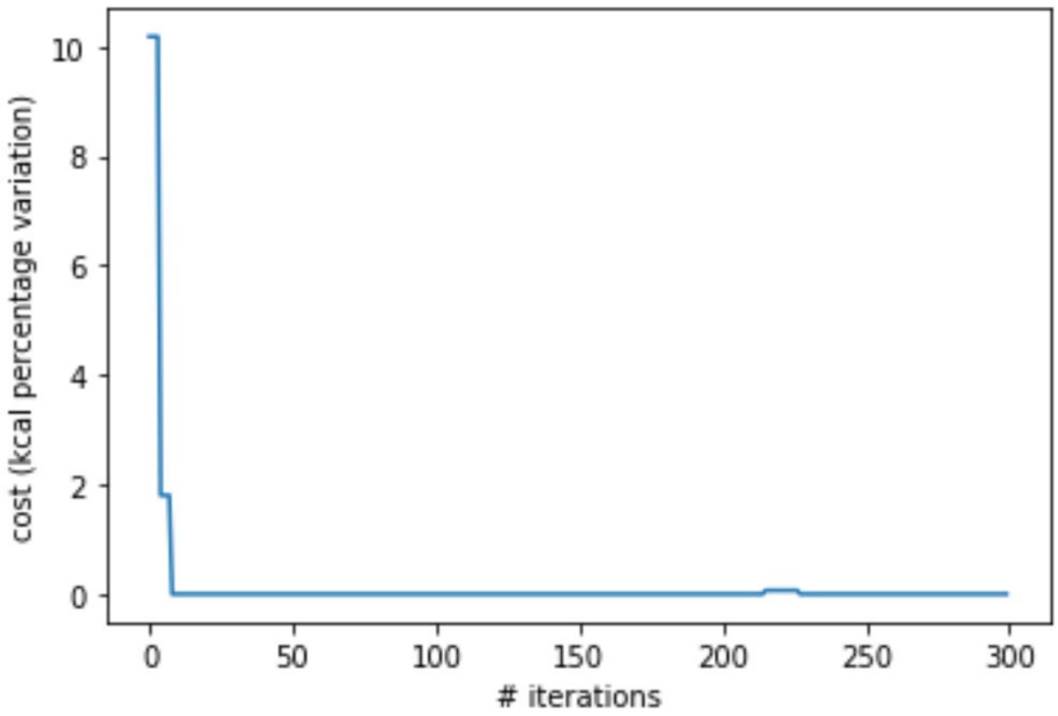
- For each algorithm:
  - A list of values are created for each parameter.
  - Run the algorithm 3 times for each combination of parameters, and record the best result.
  - Take the best result among all executions.

- Compare the results from the three bio-inspired algorithms.

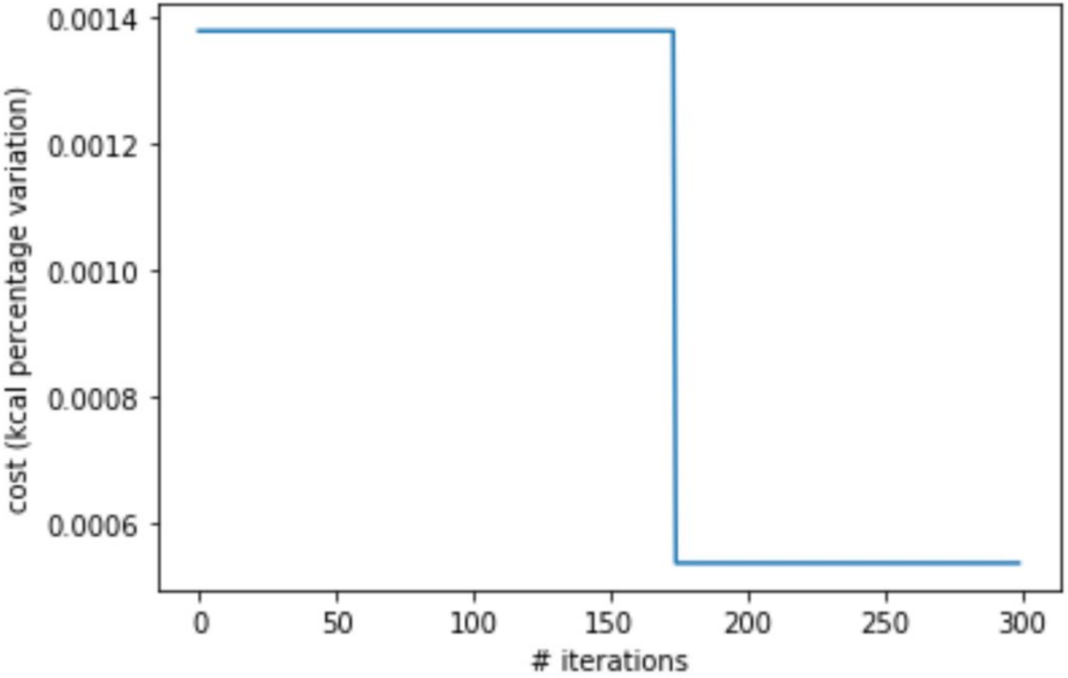
Comparative Study

Algorithms	Time to converge	Percentage variation compared to calorie goal	Parameters
Simulated Annealing	0.0076 sec	0.000539%	{k=5, lam=0.0005}
Particle Swarm Optimization	9.154 sec	0.000539%	{particles_swarm=100, num_of_swarms=4}
Firefly Optimization	0.154 sec	0.001376%	{gamma=1, flies=25}

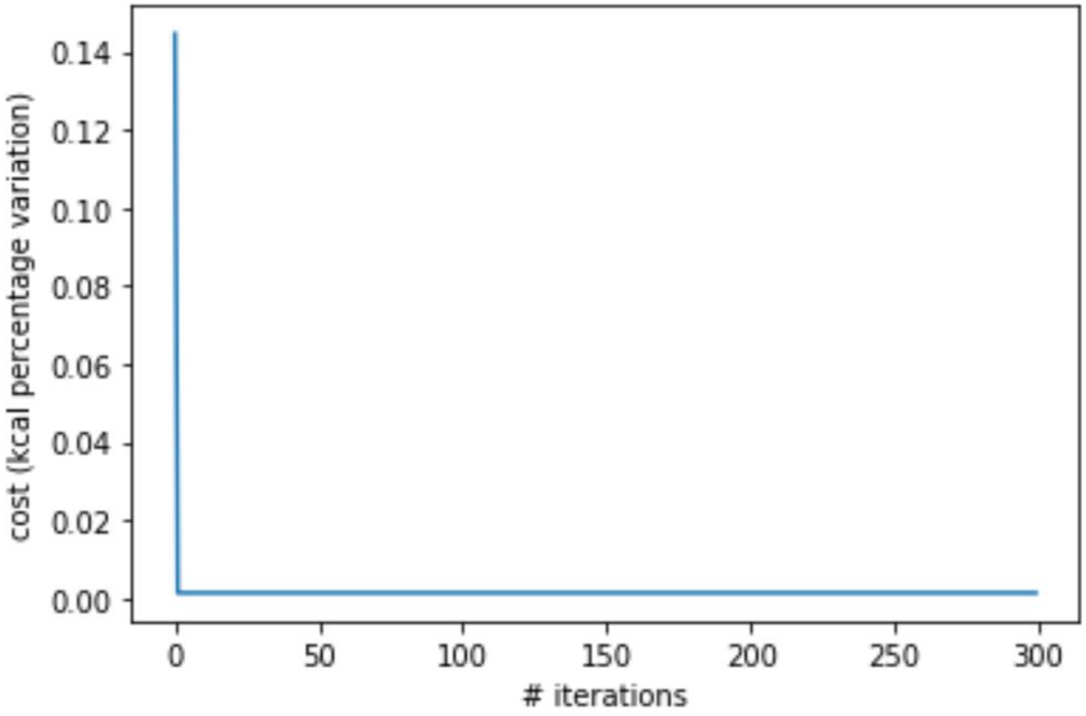
Simulated Annealing



Particle Swarm Optimization



Firefly Optimization



Demo of Result

Example of Final Route

Conclusion and Future Work

Conclusion

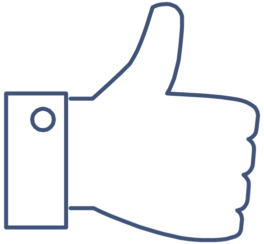
The routes generated using the algorithm has the following properties:

- + Highly accurate calorie consumption.
- + Suited for cycling.
- + Low wait time for traffic lights.
- + Smooth road surfaces.

- - More repeated path than desired.
- - More hard turns than desired.

Future Work

- Use A* algorithm instead of Dijkistra to find the fittest route between each pair of points.
- Select POIs using amenity tags like parks or community centers for better cycling experience.
- Penalize turns, especially left turns, so that the generated routes are safer.
- Penalize repeated paths, so that the generated routes are more refreshing.



THANKS!

Any questions?

Related Works

Practical Multicriteria Urban Bicycle Routing

- Mainly tackles transportation based (from point A to point B) bicycle routing problems.
- Criteria: time, elevation and comfort.
- Algorithm: the combination of multi-criteria label-setting algorithm and some heuristic speedup techniques

https://ieeexplore.ieee.org/abstract/document/7519077

Conflation of OpenStreetMap and Mobile Sports Tracking Data for Automatic Bicycle Routing

- Mobile sport-tracking app to retrieve exercise routes from multiple different users with recording their history.
- Criteria: total elevation gain, landscape, turns, the intersection with traffic and historical data.
- Algorithm: the advanced HMM(Hidden Markov Model)

https://onlinelibrary.wiley.com/doi/full/10.1111/tgis.12192

Multi-Objective Design of Time-Constrained Bike Routes using Bio-inspired Meta-Heuristics

- Find the best balance between the distance of the route and the safety level of the route.
- Criteria: time, elevation and comfort.
- Algorithm: four population-based bio-inspired meta-heuristics and the OpenTripPlanner (OTP)