AM207: Advanced Stochastic Optimization

Finding the optimal location for a bike lane

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Abstract

Towards preservation of the environment, ideally all local destinations would be accessible by bike. However, most streets in Boston were constructed with only cars in mind, and it is financially and practically infeasible to add bike lanes to all streets. Focusing on **Somerville** we ask the question,

where is the optimal location to construct a new bike lane?

Because we're interested in an extremum, not an entire distribution, the method of optimization we've selected is simulated annealing.

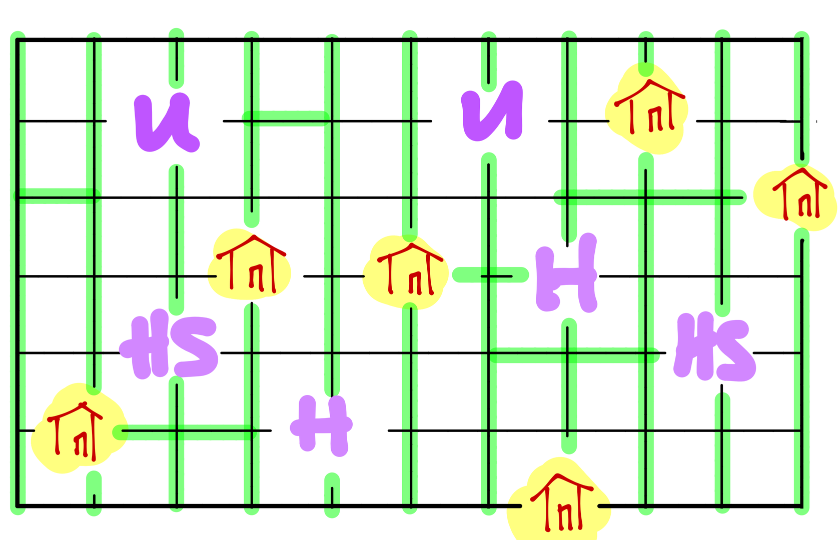
Model

Simple system to model a city

People arise from *sources* (i.e., their residences) and uptake is into *sinks* (i.e., potential destinations). Considering the most common destinations for residents of our target area, we've limited potential destinations to be schools (universities and high schools) and hospitals.

The city itself is represented as a grid where the intersections are all one unit apart and one may only travel horizontally or vertically, not diagonally.

We also assume that all vertical roads have bike lanes.



Given a list of coordinates corresponding to a fixed number of sources generating N persons and an additional list of coordinates corresponding to a fixed number of destinations/sinks, our **goal** is to find the best place to build one bike lane such that we minimize the total distance traveled by all N persons.

In this simplified model, we're assuming that

⋆ cycling is the only mode of transportation,

⋆ cycling is only possible on roads with bike lanes,

⋆ the path from source to sink consists of bike lanes and non-bike lanes, and a person is only allowed to travel on bike lanes.

Objective function

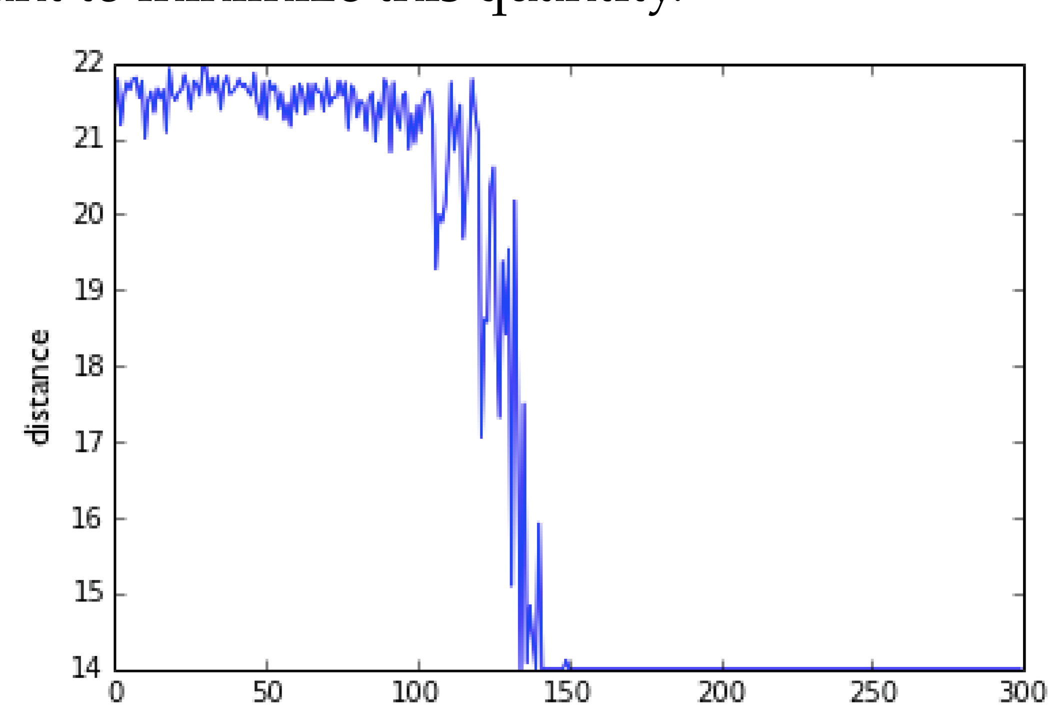
The objective function is $-\exp\{-\beta D\}$, a measure of the distance from source to sink where D is the total minimum distance summed over N persons for a given grid configuration and β is a tuning parameter.

Additional considerations include (1) flow of bikers, (2) flow of cars, (3) cost of bike lane installation, (4) travel time on bike lane, (5) travel time off bike lane, and (6) accessibility to the most number of people. However, the structure of our system causes some of these to be unnecessary or redundant, so we only consider travel time and accessibility.

Optimization procedure

The **simulated annealing** approach was selected because we are interested in finding the global optimum over a large search space, rather than characterize an entire distribution. This methodology borrows its name from annealing in metallurgy and terminology from thermodynamics.

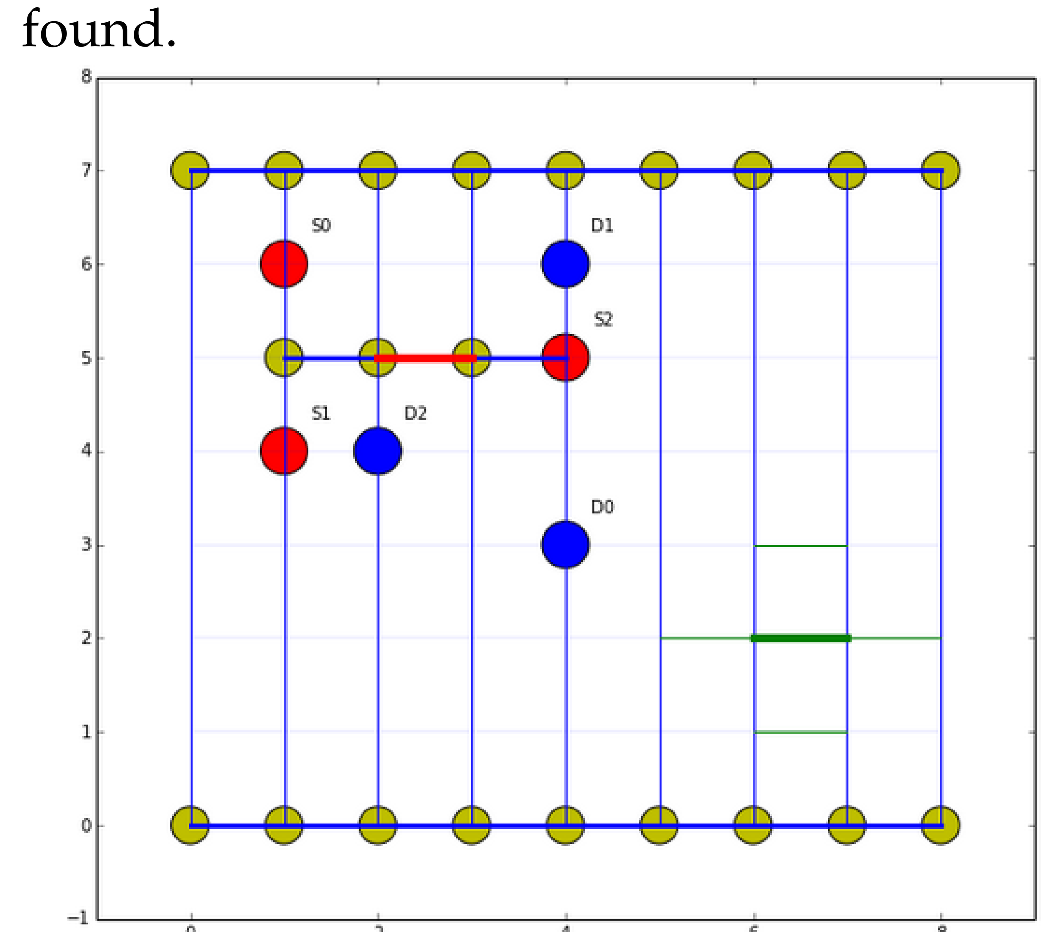
The objective function is system energy, and we want to minimize this quantity.



Implementation

We assume that we are given the locations of an individual's home and destination. We are also given the locations of existing bike lanes. Now:

1. For each individual, calculate the shortest distance by bike from home to destination. Take the sum of these distances, and compute the objective function for this sum D.
2. Initialize by randomly choosing a position at which to build a new bike lane. Calculate the objective function by repeating step 1.
3. Propose a new position by shifting the current position of the bike lane one unit to the left, right, up, or down. For this proposal, calculate the objective function.
4. If the value of the objective function is "better" for the proposal, we accept it with probability 1. If the value of the objective function is "worse", then we accept it with some probability $\in (0,1)$, or discard it otherwise.
5. Repeat steps 3 and 4 until an extremum is found.



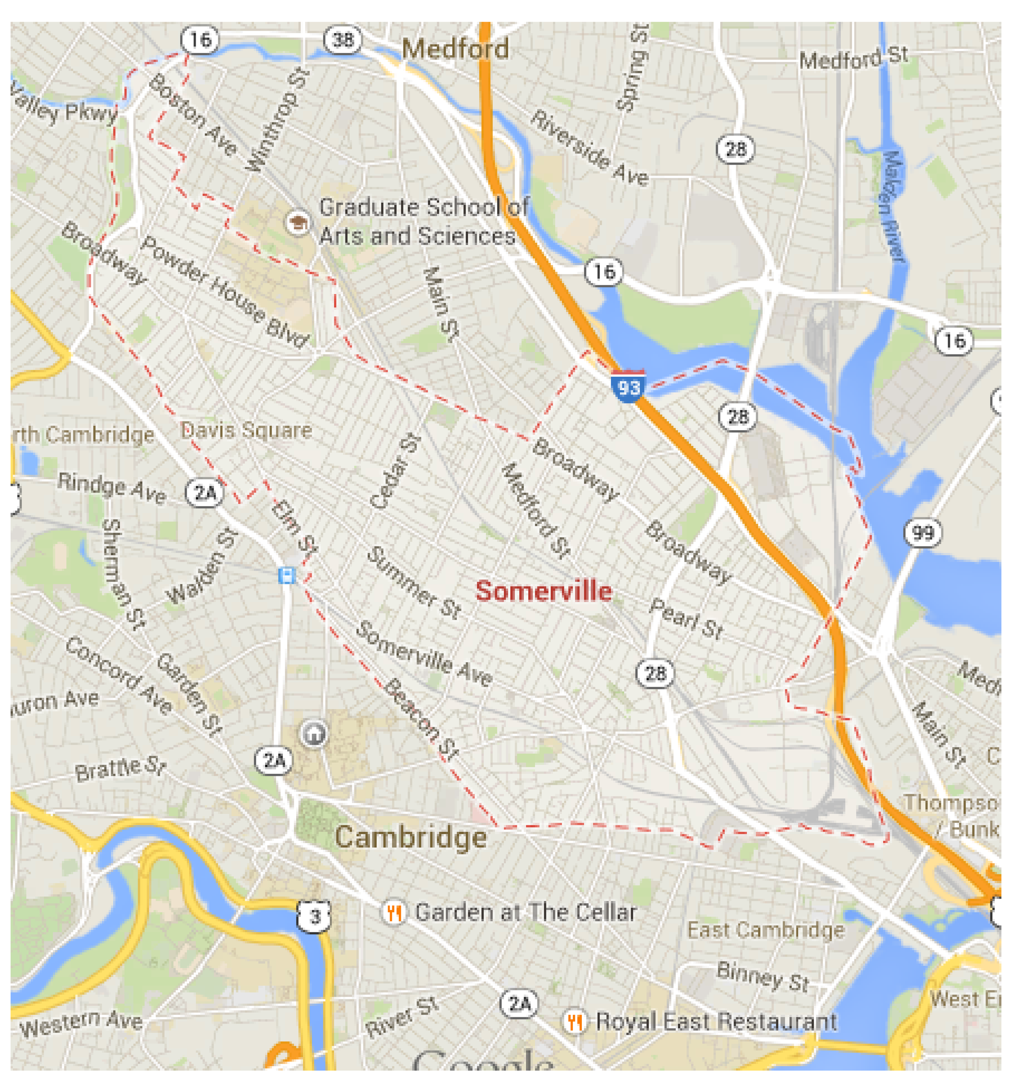
As we can see from the figure above, we have 3 sources and 3 destinations. The two thick blue line segments are existing bike lanes, the red line is the optimal place to place a new bike lane. The algorithm starts from a random position on the graph, and a new position is proposed adjacent to it. The algorithm repeats itself until it finds the optimal position, which is defined to be the position of the bike lane that minimizes the average distance traveled by all individuals.

Results

We tested the algorithm above on a toy dataset, by picking start and end points for a fixed number of individuals. The graphic above demonstrates the randomly selected set of sources and sinks, and we used our algorithm to find the optimal place to build a new bike lane. The algorithm selected the "correct" placement.

Future Directions

Using Somerville population data from US Census Bureau tracts, we hope to apply our algorithm to real data to see whether we can produce a solution of societal benefit. As seen below, Somerville can be approximated by a 4×12 grid.



This will require the addition of several sophistications to the model, including considerations of car and bike flow, cost of bike lane installation, and amount of travel time off bike lane.