Demonstration Abstract: Health-Optimal Routing in Urban Areas

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ABSTRACT

The availability of novel, high-resolution pollution maps enables a wide range of new application scenarios, which were not possible before. In this paper, we combine high-resolution pollution maps available for the city of Zurich, Switzerland, with road network data to analyze how much urban dwellers can reduce their exposure to air pollution by not taking the shortest path between origin and destination but a healthier and slightly longer alternative route. We introduce a new weight function to assess the exposure on each street segment and evaluate the benefits of the healthier path. Finally, we efficiently implement the algorithm as stand-alone application for iOS and Android devices. The app helps city residents to understand and reduce their exposure to air pollutants.

1. INTRODUCTION

Many companies offer route planning services (*e.g.*, GoogleMaps, MapQuest, TomTom) that evaluate the best route between origin and destination based on different criteria, such as distance, journey time, and least total fuel consumption. However, the general public, especially pedestrian and cyclist commuters, are increasingly concerned about the adverse health effects of urban air pollution and, hence, wish to minimize their exposure to airborne pollutants [1]. Up to today, the lack of spatially resolved pollution data hinders route planners to provide such kind of air pollution related services.

In this paper, we make use of novel, high-resolution pollution maps of ultrafine particles (depicted in Fig. 1(a)), which became recently available for the city of Zurich, Switzerland [2, 3]. We derive a novel cost function for all street segments of the city's road network (see Fig. 1(b)) to assess the expected exposure to ultrafine particles when traversing the city. We implement this new cost function in a pathfinding algorithm and compare the health-optimal routes to the traditionally used shortest path routes to analyze the potential of reducing the number of inhaled particles. Finally, we efficiently implement the algorithm as stand-alone iOS[1] and Android[2] applications for health-optimal route planning.

[1]iTunes App Store: `http://goo.gl/nRKptn`
[2]Google Play Store: `http://goo.gl/7yVK3D`

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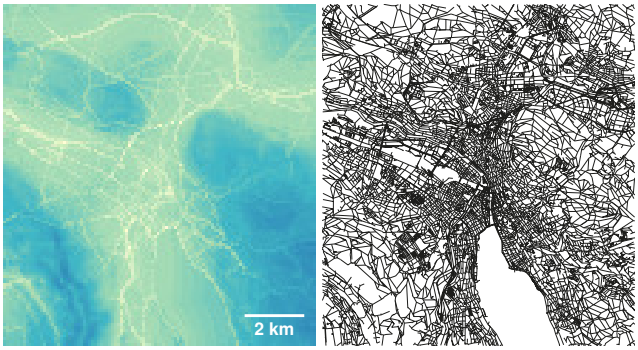


(a) Pollution map. (b) Road network.

Figure 1: Pollution map (spatial resolution of 100 m x 100 m) and road network of the city of Zurich, Switzerland.

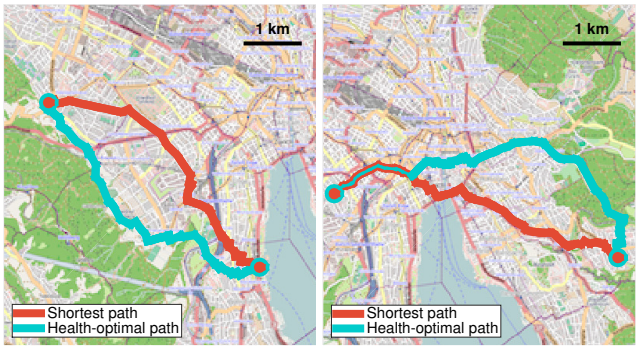
2. ROAD NETWORK GRAPH

We use data from OpenStreetMap to construct a graph of Zurich's road network. We export the city's area in the OSM XML file format and process the data with our road network graph builder to create a graph of the road network. Depending on which type of road network is needed (*e.g.*, for pedestrians, cyclists, or car drivers) a different graph is generated.

We represent the road network with an undirected graph G comprising a set V of vertices (nodes), a set E of edges each connecting a pair of nodes, and two sets of edge weights W_d and W_p. Each node $v_i \in V$ represents a crossroad or a dead-end street of the road network. There is an edge $e_j \in E$ between two nodes of V if the nodes are directly connected by a road segment (*i.e.*, without a crossroad in between). Each edge is associated with two weights. Weight $w_{d,j} \in W_d$ denotes the length of the road segment between the pair of nodes connected by edge e_j. Weight $w_{p,j} \in W_p$ denotes the expected pollution exposure on the road segment represented by edge e_j. We assume that the travel time between two nodes of an edge $e_j \in E$ is proportional to the distance $w_{d,j}$. The number of particles a human inhales is proportional to the time of exposure. Hence, we multiply the pollution concentration along edge e_j with the length of the corresponding road segment

$$w_{p,j} = \sum_{k=1}^{n} d_{j,k} \cdot c_k, \tag{1}$$

where n is the number of 100 m x 100 m grid cells the edge penetrates, $d_{j,k}$ is the length of edge e_j penetrating grid cell k, and c_k is the pollution concentration in grid cell k. The sum of the n subsegments is equal to the total length of the road segment, *i.e.*, $w_{d,j} = \sum_{k=1}^{n} d_{j,k}$.



(a) Albisrieden to Wollishofen. (b) Wiedikon to Witikon.

Figure 2: Two exemplary source-destination pairs. In (a) the shortest and health-optimal routes are completely different while they partly overlap in (b).

We use all road segments available (including those only accessible by pedestrians) to create graph G representing the road network of Zurich consisting of $|V| \approx 27,000$ nodes (*i.e.*, crossroads and dead-end streets) and $|E| \approx 74,000$ edges. We implement the widely used A* pathfinding algorithm to find the least-cost path between two nodes of the road network with respect to the two weight metrics introduced.

3. COMPARING SHORTEST PATHS TO HEALTH-OPTIMAL PATHS

In the following, we study how much urban dwellers can reduce their pollution exposure by not taking the shortest but the health-optimal path between two arbitrary locations in the city. We randomly pick from the road network graph 1000 source-destination pairs. We require a minimum straight-line distance of 5 km between source and destination nodes to prevent very short paths where with high probability the shortest and health-optimal paths are identical. For these 1000 source-destination pairs we compute least-cost paths using the A* pathfinding algorithm for both edge weights introduced. Then, we compare the length and the pollution exposure of the two routes.

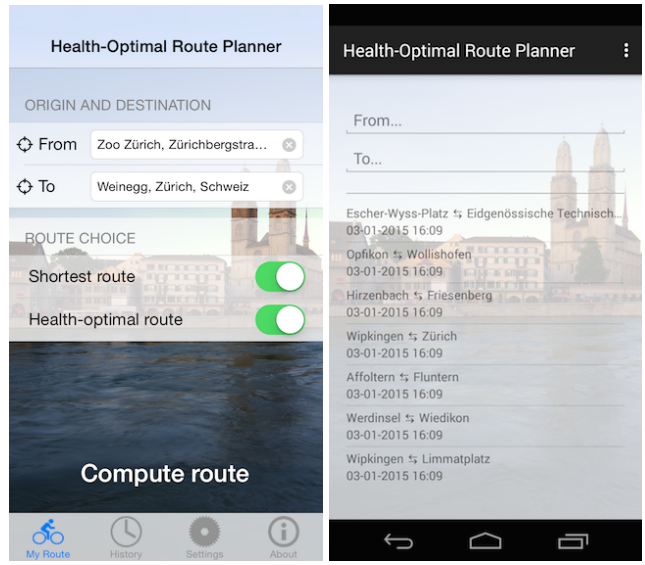
We find that taking the health-optimal path instead of the shortest path yields an exposure reduction of 7.1 % ($6.8 \cdot 10^6$ particles/cm^3·m) on average. This comes at a price of longer travel distances, the length of the health-optimal path is 6.4 % (548 m) longer on average. However, the difference between the shortest and health-optimal paths largely depends on the given source and destination nodes, as illustrated in Fig. 2.

4. SMARTPHONE APPLICATION

We implement the application in iOS for iPhones/iPads and in Java for Android devices, as depicted in Fig. 3. The application is available for free on the iTunes App Store and Google Play Store as *hRouting–The Health-Optimal Route Planner*. The source code is available on GitHub under the GNU GPL license v3.[3]

To be accepted by the users, it is essential that the smartphone application is reactive. Long computation times must be avoided as much as possible. Therefore, it is important that we efficiently implement the least-cost pathfinding algorithm. We achieve this by using simple data structures (mainly integer arrays and priority queues) and primitive data types, *e.g.*, we do not use the more

[3] `https://github.com/dhasenfratz`



(a) iPhone/iPad app. (b) Android app.

Figure 3: The health-optimal route planner application.

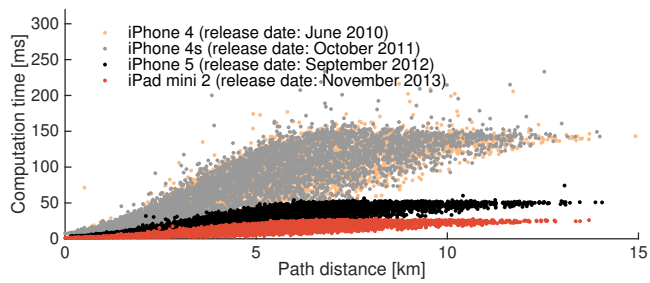


Figure 4: Least-cost path computation times on an iPhone 4 and iPhone 4s (both on average 80 ms), iPhone 5 (on average 28 ms), and iPad mini 2 (on average 14 ms).

sophisticated, but higher overhead inducing, object-oriented data structures of Objective-C. We time the execution times for 5000 random source-destination pairs on various iOS devices. The application computes a route within 28 ms on an iPhone 5 (release date September 2012) on average, as depicted in Fig. 4. The older iPhone 4 and 4s (release date June 2010 and October 2011) have considerably longer computation times with 80 ms on average, while the newer tablet iPad mini 2 (release date November 2013) is very fast with an average computation time of 14 ms. This shows that even the oldest iPhone generation supported by our application is able to compute the majority of routes in the benchmark set in less than 150 ms, enabling a smooth interaction with the application.

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5. REFERENCES

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