Wrocław University
of Science and Technology

Network Science

HOW TO PLAN BICYCLE PATHS

Michał Maternik, Piotr Rarus, Kornel Romański
Wrocław University of Science and Technology
michal.maternik@gmail.com, piotr.rarus@gmail.com, kornel.ro@gmail.com

Background

Wrocław has 200 km of bicycles paths, what gives citizens one of biggest infrastructure in Poland. There are different types of paths, like separate paths, paths on the car lines, paths through parks. They meet both transport and tourist needs. Despite the extensive paths network, users point problems such as:

- insufficient paths network in city center
- lack of system consistency: there is no possibility of free passage between districts and access to the center

Idea

Decision making about cycling infrastructure should lead to effective improvement of the quality of the existing road network. This can be done based on existing data, analyzing bicycle routes as a network of connections. Using this knowledge in our project, we would like to answer the following questions:

- Where to build the new paths?
- How can we maximize the efficiency for a given cost?

Using network science knowledge we decided that bike paths network is better if:

- it has **lower average betweenness centrality** - we want to minimize situation that few paths are much more crowded than others, so our goal is to get more equal usage of all paths,
- it has **lower average shortest path** - it's natural that we want to move around the city faster,
- it has **lower clustering coefficient** - more clustered paths mean that we can efficiently move around one place but we prefer to build new paths where there is lack of infrastructure.

Considering the above, after building a network of existing bicycle paths and generating new possible connections, we can choose those that will give us a better solution for given constraints.

Data

To solve the problem we built bike paths network using open Wroclaw data and generated new possible paths based on city car roads map cut from OpenStreetMap. This approach gave us big network with ~77000 bike paths (red) and ~440000 possible new paths (black). After data processing (among others: graph smoothing - remove nodes dividing straight paths, selecting possible paths connected with bikes paths and their few neighbors) we have reduced number of possible paths to ~90000 what was still computationally difficult so we focused only around district Leśnica (black square, after additional processing ~600 possible paths).

Figure 1: Prepared networks

Optimization

We have used genetic algorithm to solve the problem of building no more than 10 km new bike paths. After extracting graph of possible paths we code solution in binary fashion, where each gene corresponds to one edge in the graph. Gene with value *True* means that edge should be added to the newly built graph. Gene with value *False* means that the edge will not be added.

Algorithm 1: Genetic algorithm pseudocode

```
population=initialize();
max_epochs = N;
epoch = 0;
while epoch < max_epochs do
    population =
     crossover(population);
    population = mutate(population);
    population = fix(population);
    evaluate(population);
    population =
     tournament(population);
end
```

Solution is initialized by setting adjacent genes to value *True* to produce graph of *10%* max paths length. It's based on an assumption that adjacent genes should produce adjacent edges on a graph, thus creating a continuous path. *Crossover* operator takes a pair of random solutions and produces a pair of offsprings, that are added to new population. *Mutation* operator takes a random solution and flips random block of bits. Next operator fixes the solution to match the constraint by removing path block until constraint is met.

Genetic algorithm ensures population convergence by putting selective pressure on it. In our solution we use *tournament* selection procedure. It is very easy to implement and is immune to fitness scaling issues. Procedure then is repeated for a given number of *epochs*.

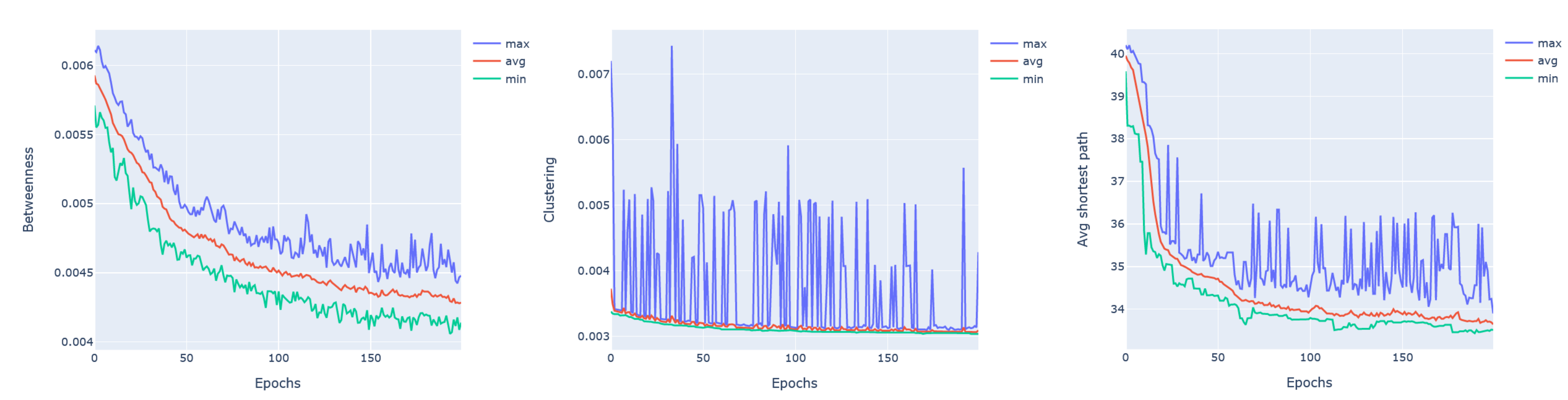

Figure 2: Convergence

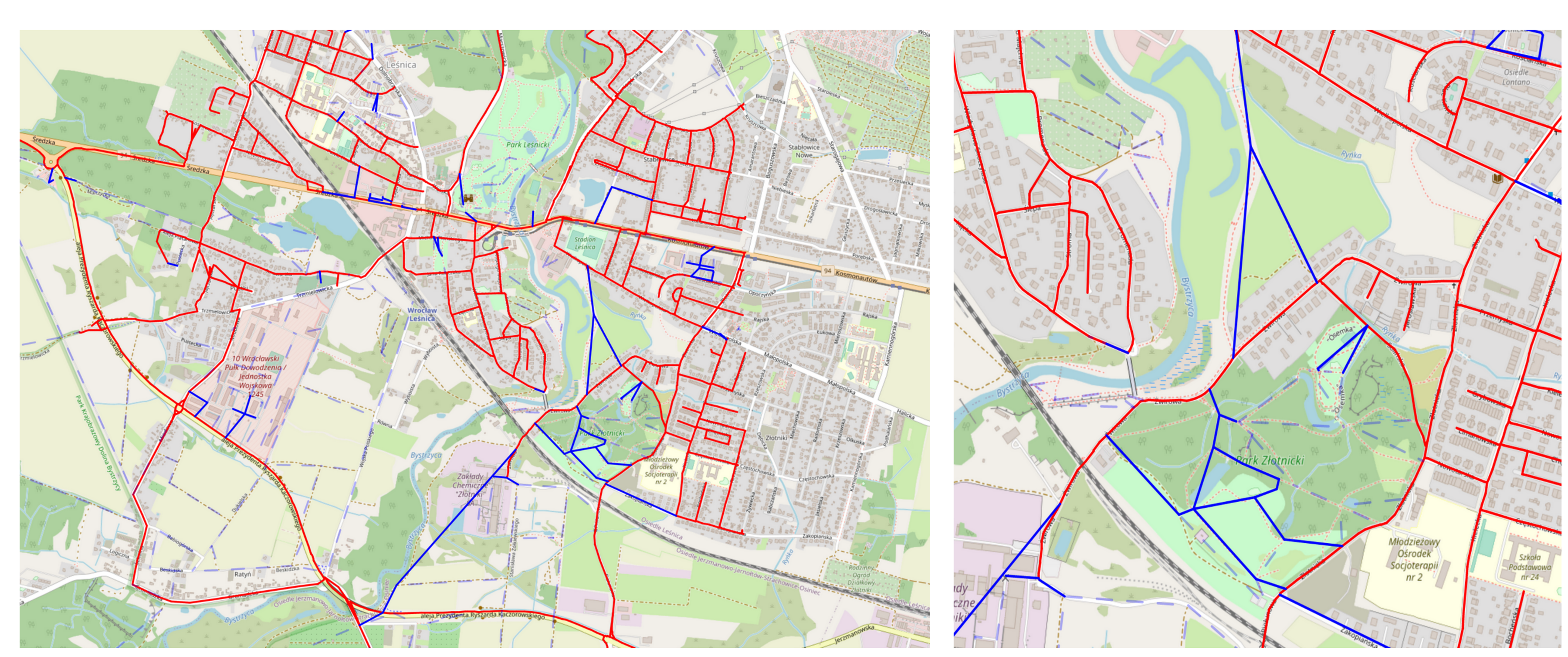

Figure 3: Results for average betweenness centrality metric

Conlusions

The maps above present exisitng bike paths (red) and new paths chosen to build (blue) based on average betweenness centrality metric, which was most promising. We can see that algorithm found best paths that connect far apart network parts what agrees with intuition.

Genetic algorithm results in a population of solution, which may be similar in fitness quality, but structurally different. We created an app which visualizes a solution and gives user an ability to fix some paths manually. It mainly serves a purpose of visualizing a new paths concept which is mostly promising in respect to optimized metric.

Genetic algorithm proves to be viable method to modify a graph with respect to specified metric, though due to large solution space (over 2^{600}) we were unable to search it thoroughly on a single machine.

Results obtained for small area are proof of concept that looking on roads as network of connections and optimization methods can be good way to efficient data based decision making.