

# slimmer

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## Abstract

This document describes the solver, we submitted to the heuristic track of the PACE 2024 competition under the user name “slimmer”. The task of the competition is to solve the one-sided minimum crossing problem. For this, we employ a large neighborhood search heuristic.

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**Keywords and phrases** Large neighborhood search, One-sided crossing minimization

**Supplementary Material** The source code is available on GitHub (TODO:URL) and Zenodo (TODO:URL).

## 1 Introduction

In the one-sided minimum crossing problem, a bipartite graph  $G = (A \cup B, E)$  is given with node partitions  $A = \{l_1, \dots, l_L\}$  and  $B = \{r_1, \dots, r_R\}$  and edges  $E$ . It is assumed that the graph is drawn, where the nodes are drawn in two parallel lines - one line with the nodes in  $A$  and one line with the nodes in  $B$ . The task is to compute an order in which the nodes in  $B$  are drawn, which minimizes the number of pairwise crossings of edges in the drawing. Thus, a potential solution is a permutation of the nodes in  $B$  (or their indices, respectively).

We employ a large neighborhoods search (LNS) heuristic [3] to solve this problem. LNS is a popular heuristic for solving combinatorial optimization problems. Starting with an initial solution, it iteratively destroys and repairs the current incumbent solution (i.e., the best solution found so far). If the resulting solution is better than the incumbent, it is used as new incumbent and otherwise it is rejected. In our case, the destroy and repair simply removes and reinserts nodes from/to the permutation. We employ a restart strategy to avoid premature convergence and a segmentation strategy to handle large problem instances. The solver is implemented in C/C++. The following section describes the solver more in detail.

## 2 Solver Description

### 2.1 Destroy and Repair Operators

Destroy and repair operators are used to remove and to reinsert nodes from/into a given (partial) solution. We employ two different destroy operators:

- Random destroy, which removes randomly selected nodes from the given solution, and
- Block destroy, which randomly selects and removes a contiguous sequence of nodes from the current solution.

For the repair, we also employ two different operators:

- Random insertion, which reinserts nodes at randomly selected positions of the current solution, and
- Greedy insertion, which reinserts each node at the (lowest) position that results in a minimum increase of the number of edge crossings.

Both repair operators reinsert the nodes in the order in which they are passed to the operators.

## 2.2 Initialization

We compute an initial solution by inserting all the nodes of  $B$  in increasing order of their indices in an at the beginning empty solution with help of the greedy insertion operator.

## 2.3 Main Loop

In the main loop, we randomly select between random and block destroy for removing nodes from the current incumbent solution. Random destroy is selected with a probability of 20% and block destroy is selected with a probability of 80%. If random destroy is selected, the number of nodes to remove is sampled uniformly random between 100 and 150. If block removal is selected, the number of nodes to remove is fixed to 50 and the removed nodes are randomly shuffled before they are passed to the repair operator. For the repair, greedy insertion is used. If the repaired solution has a lower or equal number of edge crossings than the incumbent solution, it is accepted as new incumbent and otherwise it is rejected.

## 2.4 Prevention of Premature Convergence

LNS is a rather local search heuristic and especially in combination with a greedy repair strategy, it is prone to getting stuck in a local optimum. A common countermeasure is to add random noise to the objective function in order to make the repair less greedy [2]. However, since we found this strategy to be not beneficial for the given problem, we employ another approach for preventing premature convergence: We do not only keep track of one incumbent solution, but two - a global incumbent and a local incumbent. The global incumbent is the best solution encountered so far. The local incumbent is the solution, the main loop is currently working on and it might differ from the global incumbent. At the beginning of the search, the global and local incumbents are identical. Whenever the number of consecutive iterations of the main loop, which did not yield an improvement of the local incumbent solution, exceeds a certain threshold (set to 2000 in the submitted solver), a new local incumbent is computed by slightly worsen the current global incumbent and the counter for unsuccessful iterations is reset to zero. More precisely, the new local incumbent is computed by removing 20 nodes from the global incumbent with the random destroy operator and reinserting the removed nodes with the random repair operator. Hence, whenever the search makes no more progress, it is guided away from the current local optimum without having to restart completely from scratch.

## 2.5 Performance Improvements

In order to be able to construct and to evaluate a high number of solutions in a short time, we applied different techniques to improve the performance. One of these performance improvements is that we precompute a crossing matrix  $C$ , where element  $c_{ij}$  of the matrix is the number of crossings between edges of nodes  $r_i$  and  $r_j$  if node  $r_i$  appears before node  $r_j$  in the permutation. With help of the crossing matrix, a solution can be evaluated very quickly and it allows to determine quickly how the number of crossings changes if a node is shifted from a position  $k$  to the next position  $k + 1$  in the greedy insertion operator.

Another performance improvement is that we do not evaluate a new solution, which is created in the main loop, from scratch. Instead, we update the objective value in the destroy and repair operators based on the operations, which are performed by the operators. If, for example, a node  $r_j$  is removed, the number of crossings is reduced by the number of crossings between edges of node  $r_j$  and edges of all other nodes of the current solution.

84 Furthermore, we applied different improvements on the code level, like loop unrolling  
 85 or storing and using a transposed version of the crossing matrix in addition to the original  
 86 matrix in order to make memory accesses more efficient.

## 87 2.6 Handling of Large Problem Instances

88 For large instances, we cannot compute the crossing matrix since this is too time and memory  
 89 consuming. Without crossing matrix, the evaluation of solutions and the greedy insertion  
 90 operation becomes time consuming. Thus, we employ a special strategy to handle large  
 91 instances with 15,000 or more nodes in  $B$ : If the number of edges exceeds 300,000, we  
 92 compute an initial solution with the Barycenter heuristic [1] and otherwise an initial solution  
 93 is computed via greedy insertion similar to the smaller instances. We then further optimize  
 94 the solution segment-wise. We first divide the solution into contiguous segments of 2000  
 95 nodes and optimize the order of the nodes in each segment analogous to smaller instances  
 96 as described in the previous subsections. Per segment, 1000 iterations of LNS are executed.  
 97 The segment-wise optimization is repeated until the time limit is reached (or a solution with  
 98 zero crossings is found) and in each repetition, the segment size is increased by 1000 up to a  
 99 maximum of 5000.

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