MulTyLink: Multiple Type Linkages

User Manual (version 2.0.2)

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1. Introduction

MulTyLink (Multiple Type Linkages) is a C++ open source program, licensed under the GPL v3, to define linkages between terminals of the same type.

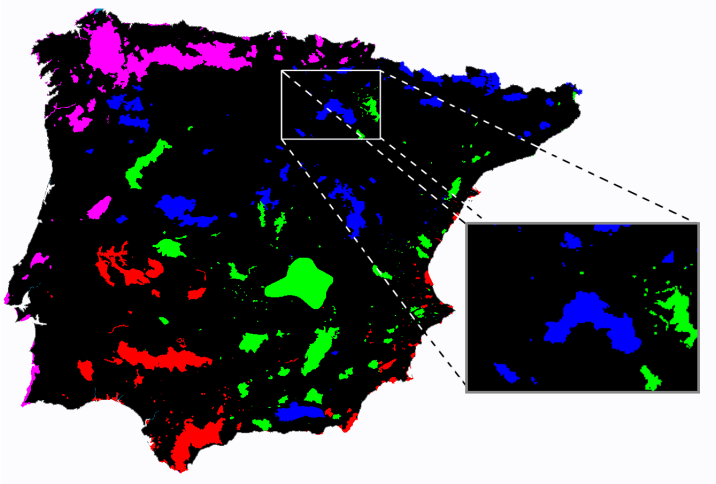
Given a map, viewed as a set of cells in which subsets T_k, called *terminals* of type k ($k = 1, 2, \ldots, m$), exist, MulTyLink links (if possible) all terminals of type k not using cells which are considered inadequate for linkage, called *barriers* for type k, and assuming a type k adjacency relation for pairs of cells. We call these linkages *feasible*. A cost is associated to every nonterminal cell, and the goal is to find a minimum cost feasible linkage (i.e., minimizing the sum of nonterminal cells).

An application is the linkage of climatically-similar protected areas (PA) in the Iberian Peninsula (IP) addressed in Alagador et al., 2011[1]. Terminals are (80,871 1km $\times$ 1km cells intersecting) 681 PA in IP (represented as 580,696 1km$\times$1km cells), which were clustered into four groups sharing similar climates. For each climatic type, barriers were defined as the cells that significantly differ from the mean climatic conditions of that type, and an adjacency rule between cells was defined in order that continuous linkages were obtained. A cost was assigned to every non protected cell that is proportional to the cell's fraction not covered by Natura 2000 Network.

The rational for the identification of linkages between climatically-similar protected areas, free from climatic barriers, stands on the assumption advocated by Alagador et al., 2011[1] that species with similar ecological requirements occupy the same environments. Thus, linking at minimum cost climatically-similar protected areas is a cost effective way to promote the dispersal of species, counteracting in part the negative effects of fragmentation.

To illustrate the usage of MulTyLink we will use an image clip of the IP data deemed by Alagador et al., 2011[1], consisting of 100 $\times$ 100 cells (Figure below).

[1]Alagador et al., Linking like with like: optimising connectivity between environmentally-similar habitats, *Landscape Ecology*, 27, 291-301, 2012.



The data file concerning the region (example1.txt) is available for download at `http://purl.oclc.org/multylink`, together with the MulTyLink files.

2. Algorithms

Users can chose between two algorithms: *Type by Type* and *Grasp*.

2.1. Type by Type. For a given permutation $P = (t_1, t_2, \ldots, t_m)$ of types $k = 1, 2, \ldots, m$, the *Type by Type* algorithm starts linking terminals of type $k = t_1$, using (an adaptation for the node-weighted case of) a minimum spanning tree based approximation of the minimum Steiner tree problem[2]. Next, the cost of every cell used to link the terminals $k = t_1$ is redefined to zero, and the linkage of terminals of type $k = t_2$ is determined using the same above procedure. The procedure is repeated for types $k = t_3, \ldots, t_m$. Finally, the solution consisting of all linkages is pruned from redundant cells (i.e., cells whose removal do not increase the number of components of any type) till the solution becomes minimal.

When running the algorithm with different permutations, *Type by Type* outcomes the best among the obtained solutions.

2.2. Grasp. *Grasp* is a heuristic of the general type known as greedy randomized adaptive search procedure.

Starting with the (unfeasible) solution consisting only of all terminal cells, at each iteration *Grasp* links a pair of not yet linked terminals of the same type. The type of terminals to link is uniformly selected among the types for which terminals are not connected yet. To link

[2]The minimum spanning tree approximation consists of finding a minimum spanning tree on a complete graph whose nodes are terminals and where the weight of every edge (u, v) is the cost of the minimum cost path connecting terminal u to v. Every edge of the minimum spanning tree is replaced by the corresponding minimum cost path, and a minimal solution is obtained by sequentially removing non-terminal nodes, whenever removal do not disconnect terminals.

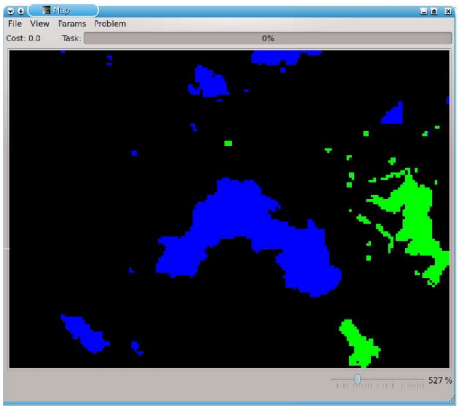
terminals of the chosen type k, a terminal s_k is uniformly selected from T_k and the path of minimum cost among the minimum cost paths (excluding barriers) between s_k and every other terminal of T_k, not yet linked with s_k, is determined. The path is added to the current solution, and the costs of its cells are redefined to zero. When all terminals of the same type are linked (or when no more linkages are possible), redundant cells (i.e., cells whose removal do not increase the number of components of any type) are removed till the solution becomes minimal.

Grasp outcomes the best solution among the solutions obtained from an arbitrary predefined number of runs.

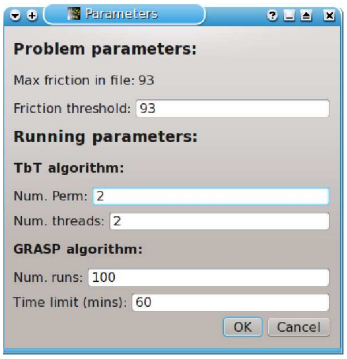
3. Program interface

Start the program and the main window will appear. Use File→Open to read your data (see Section 4 for the format of the input file).

While reading the file the log window displays information about the data read. After reading the data the map window will appear.



3.1. Selecting parameters. Before solving the problem you may want to change some parameters. Go to Params→Set Params and open the window.



Each cell has a friction value that quantifies the flow resistance of the cell. The window displays the maximum value of the frictions specified in the file and allows you to specify a threshold to used. Non terminal cells with friction values exceeding the threshold are not considered for linkages.

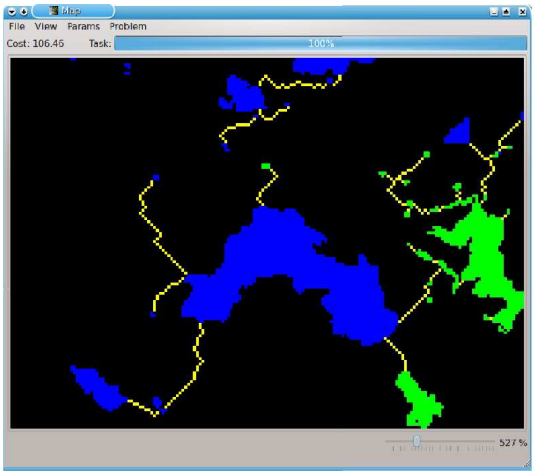
The *Type by Type* algorithm calculates one solution for each permutation of the terminals types, and returns the best solution (see Section 2). If the number of types is less or equal to 4, the number of permutations is by default settled to be equal to the factorial of the number of terminal types, and all permutations are considered. If the number of types is greater than 4, the number of permutations is by default settled to be equal to 100, and 100 uniformly selected permutations are considered. You can change the number of (uniformly) permutations in the field **Num. Perm**.

The program solves in parallel the problem for several permutations. The number of parallel solvers depends on your hardware. The field **Num. threads** contains the number of cores that the program finds in your computer. You can change the value to solve a different number of permutations in parallel. High numbers use more memory. If you have memory problems you can lower this value.

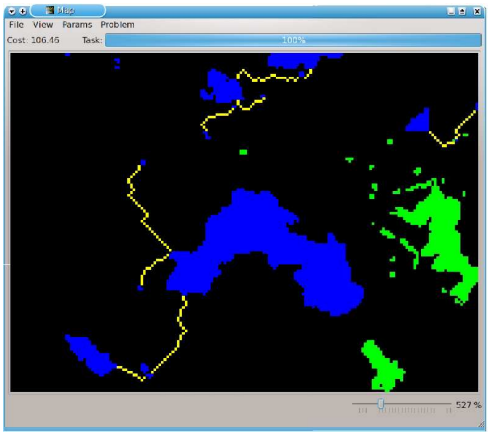
The *Grasp* algorithm calculates one random solution in each run, and returns the best solution (see Section 2). You can specify the number of runs and the elapsed time limit. (Since the time limit is only checked after each run, the execution may exceed the specified value.)

3.2. Solving the problem. To start solving the problem use the menu Problem→Solve and choose one of the two algorithms available. The *Grasp* algorithm uses more memory and may be inadequate for large problems. The progress bar will show what the program is doing. Map size and adjacency rules may render long time for solutions to be obtained. maps can take a long time to solve.

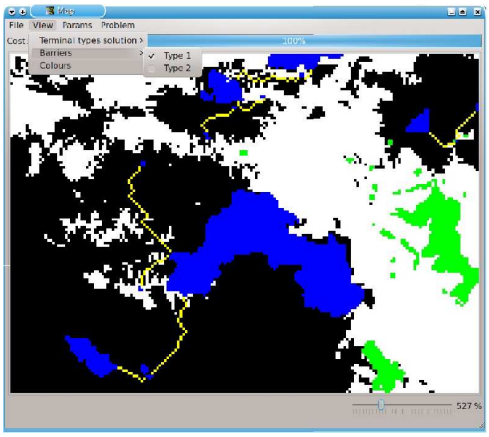
The calculated solution is depicted in yellow.



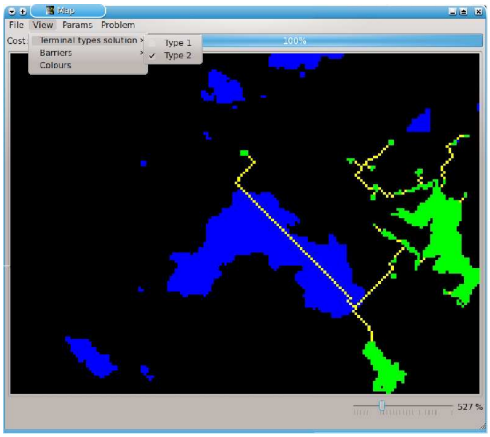
It is possible to see how a particular type of terminals is linked in the solution, choosing from the menu: View→Terminal types solution→type. The following image shows linkages for the blue type.



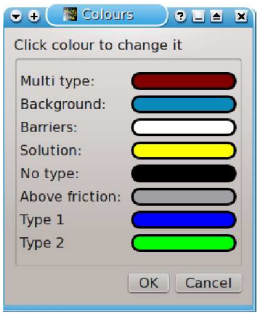
Note that not all blue terminals are connected. This is due to the blue type barriers specified in the input file that prevent the connection of all blue terminals. You can see the barriers for a particular type choosing View→Barriers→type. The figure below depicts barriers and linkages for the type blue.



The linkages for type green is shown in the next picture. In this case the path crosses terminals of type blue. Paths inside terminals are only shown if these terminals are not selected for display.



3.3. Colour selection. The program has a default set of colours but you can use your own. To change the colours go to View− >Colours and change them.



To save your colour scheme go to File− >Save colour scheme and choose a file name. You can load it any time you want for the same problem or other problems.

3.4. Cell information. To obtain information about any cell in the map just click over it. A popup window will appear with:

- id of the cell,
- cell type(s).
- cost of the cell,
- x and y coordinates.

3.5. Output. For each solution the program displays in the **log** window the following information:

- the ids of the cells in solution, excluding the terminals;
- for each terminal type:
  - the sum of costs of the selected cells,
  - the minimum friction value of the selected cells,
  - the maximum friction value of the selected cells,
  - the minimum cost of the selected cells,
  - the maximum cost of the selected cells,
  - the number of components. This represents the (minimum) number of clusters of terminals of that type that can be linked together. (If all terminals of that type are linked, the number of components is equal to 1.)
- the same information is given for the global solution;
- the wall clock time spent in solving the problem.

The information can be saved to a text file using File→Save solution.

The image displayed can be saved using File→Save image. This option will create a file with the exact image displayed in the window.

4. Input file

The program reads the data from a text file. Lines beginning with a # are ignored. Numbers in a line have to be separated by commas.

The format of the file is:

- **line 1:** Number of cells, number of terminal types.
- **line 2:** Minimum X coordinate, Maximum X coordinate, Minimum Y coordinate, Maximum Y coordinate, coordinate step, zoom factor.

  The first four values are the minimum and maximum coordinates of the cells in the file. The coordinate step is the absolute value of the sum of differences between coordinates of two contiguous cells, i.e $|X - X'| + |Y - Y'|$, for contiguous cells of coordinates (X, Y) and (Y, Y'). The zoom factor controls how the map is shown in the screen. A zoom factor of 1 uses one pixel for each cell. A factor of 2 uses 4, etc.
- **line 3:** Adjacency distances for types $k = 1, \ldots, m$. These parameters control which cells are considered to be adjacent. The distance is expressed in step units. A value of d means that cells within a circle of radius d centred on a particular cell are adjacent to it. Common values are 1 and $\sqrt{2}$. In order

to avoid rounding errors use a value a little over the desired one, e.g. 1.001 for 1 or 1.42 for $\sqrt{2}$.

- **line 4:** Names of the terminal types, one for each type. For example Mountains, Plains, Swamps.
- **lines 5-end:** Information about each cell. Each line must contain the following comma separated fields:
  - **id:** A integer that identifies the cell. Ids must be unique and in ascending order.
  - **x coordinate:** A float number with the longitude of the cell.
  - **y coordinate:** A float number with the latitude of the cell.
  - **cost:** A float representing the cost of the cell.
  - **friction:** A float that quantifies the flow resistance of the cell. It controls the conditions in which the cell can be used, e.g. the human footprint. In the program the user can specify a value such that all cells above it are discarded from the analysis.
  - **types:** The types to which the cell belongs. This should be an integer specifying the number of terminal types to which the cell belongs, followed by the types. Value 0 means that the cell is not a terminal for any type. If the cell belongs to, say, types 5 and 6 this field should contain 2,5,6.
  - **barriers:** The types for which the cell is a barrier. Should be an integer between 0 and number of types, followed by the types. Value 0 means that the cell is not a barrier to any terminal type. If the cell is a barrier for, say, types 1,2 and 6 this field should contain 3,1,2,6.

We illustrate the format of an input file showing the first lines of the file parcial-100-100.txt:

```
# Number of cells, number of terminal types
23400,2
# Min X coord, Max X, Min Y, Max Y, step, zoom factor
460500,639500,4612500,4741500,1000,6
# Adjacency distance
1.42,1.42
# Name of the terminal types
Type 1,Type 2
# Data for each cell
49409,460500,4741500,0,23,0,2,1,2
49410,461500,4741500,0,20,0,2,1,2
...
```

Disclaimer

The authors accept no responsibility for any inconvenience caused directly or indirectly by the installation or use of this software.

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