Visualisation and Analysis of Geographic Information

Algorithms and Data Structures

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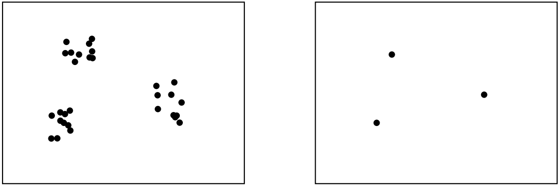
Motivation

- To develop a Web application for Geographic information system
- A QREN project with Smartgeo and UC

Motivation

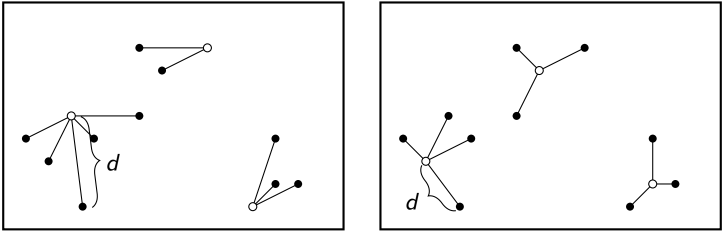
- Reduce visual information when displaying large numbers of geographic points (e.g. Points of interest)
- Find a representative subset of a collection of points in a map



- The set of points can change (zooming/panning)

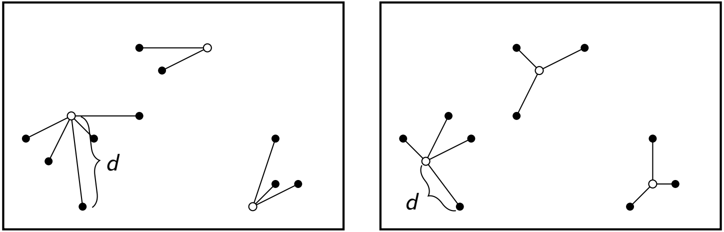
Coverage

- Minimising Coverage



Coverage

- Minimising Coverage



$$\min_{\substack{P \subseteq N \\ |P| = k}} \max_{n \in N} \min_{p \in P} \|p - n\|$$

Work Plan

- 1^{st} Semester
  - Literature Review: Geographic Information Systems, OGC Standards WMS, WFS, Map Projections, algorithms and heuristics for clustering and facility-location problems.
  - Development of a Branch-and-Bound approach.
- 2^{nd} Semester
  - Development of heuristic approaches.
  - Experimental analysis of the algorithms.
  - Integration of the algorithms in the visualisation framework through web-mapping standards (WMS/WFS).
  - Comparison between different approaches using Open Street Map data.

Integer Linear Programming

$$
\begin{aligned}
\text{minimise} \quad & D \\
\text{subject to} \quad & \sum_{j=1}^{N} y_j = k \\
& \sum_{j=1}^{N} x_{ij} = 1 & i = 1, \ldots, N \\
& \sum_{j=1}^{N} d_{ij} x_{ij} \le D & i = 1, \ldots, N \\
& x_{ij} \le y_j & i = 1, \ldots, N; j = 1, \ldots, N \\
& x_{ij}, y_j \in \{0, 1\} & i = 1, \ldots, N; j = 1, \ldots, N
\end{aligned}
$$

Branch-and-bound

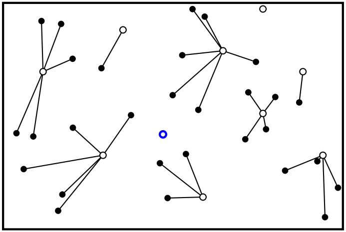
- Branching
  - Divide search space in a binary tree
  - At each step, decide if a point is a centroid or non-centroid
  - Update objective function accordingly

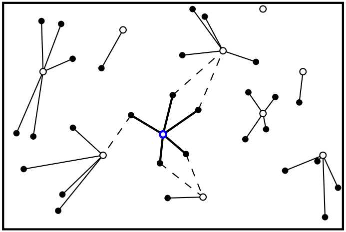
Branch-and-bound

- Branching
  - Divide search space in a binary tree
  - At each step, decide if a point is a centroid or non-centroid
  - Update objective function accordingly
- Bound
  - Assume best possible case
  - Prune tree

Branch-and-bound

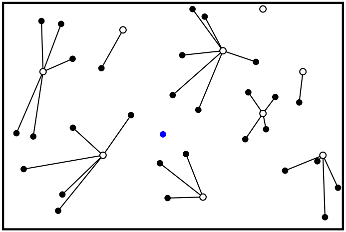
- Inserting a Centroid
  - Search all non-centroids for assignment update
  - Smaller or equal coverage value

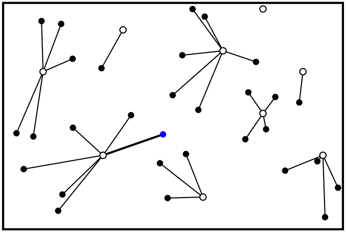




Branch-and-bound

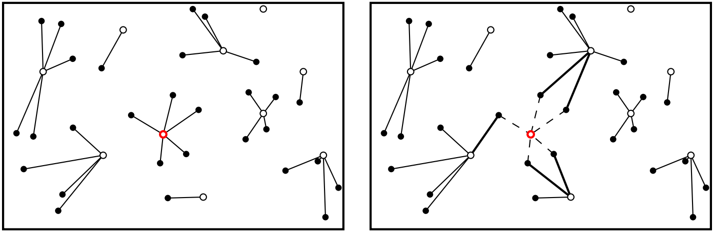
- Inserting a Non-centroid
  - Search for closest centroid
  - Larger or equal coverage value





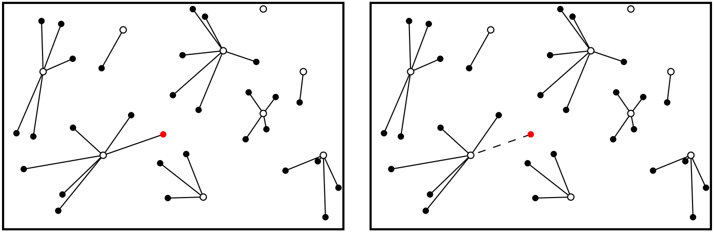
Branch-and-bound

- Removing a Centroid
  - Update all non-centroids
  - Larger or equal coverage value



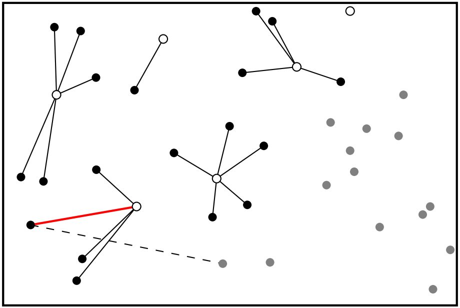
Branch-and-bound

- Removing a Non-centroid
  - Update objective function
  - Smaller or equal coverage value



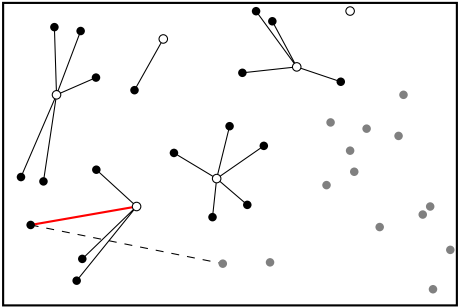
Branch-and-bound

- Applying the bound



Branch-and-bound

- Applying the bound



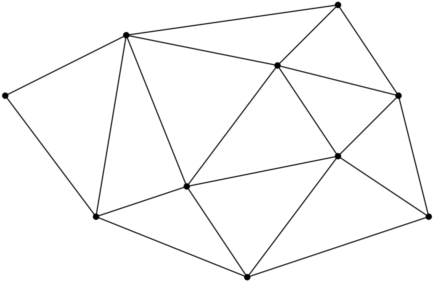
- (Only if a better solution has been found)

Geometric Approach

- Unnecessary number of calculations
  - Use geometric structures to speed-up the update of the objective function

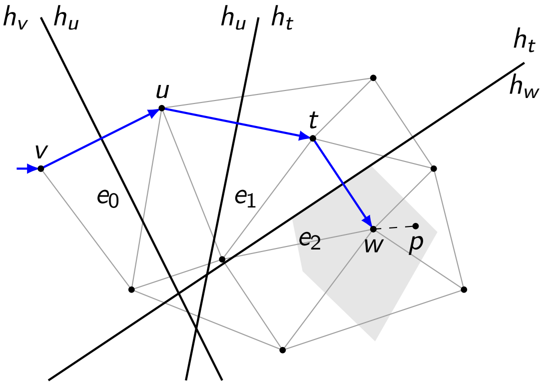
Geometric Approach

- Unnecessary number of calculations
  - Use geometric structures to speed-up the update of the objective function
- Delaunay triangulations



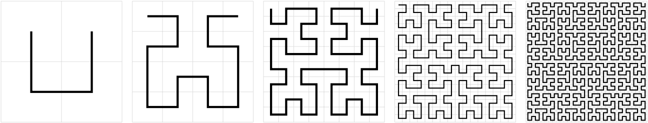
Geometric Approach

- Greedy Routing



Geometric Approach

- Greedy Routing
- Use Hilbert curves to minimise distance between consecutive routing calls

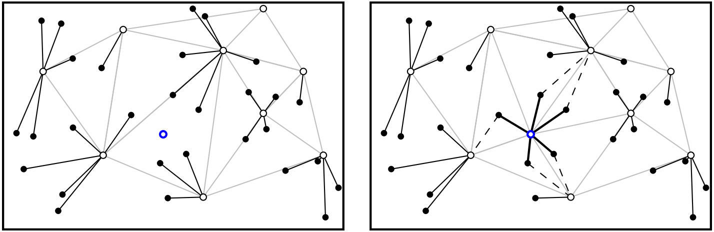


Geometric Approach

- Pre-process:
  - Initialize Delaunay Triangulation
  - Sort points by Hilbert curve

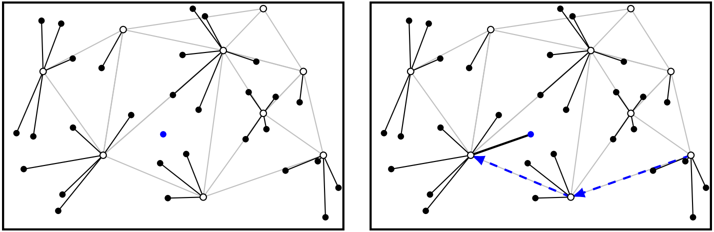
Geometric Approach

- Inserting a Centroid
  - Insert centroid in triangulation
  - Search all non-centroids for assignment update
  - Smaller or equal coverage value



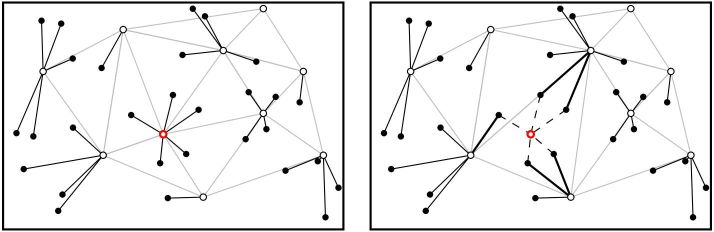
Geometric Approach

- Inserting a Non-centroid
  - Search for closest centroid using greedy routing
  - Update objective function
  - Larger or equal coverage value



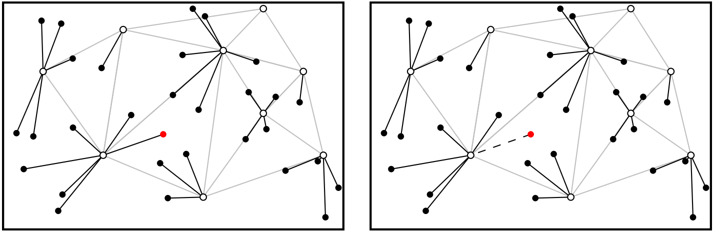
Geometric Approach

- Removing a Centroid
  - Revert assignment
  - Remove centroid from triangulation
  - Larger or equal coverage value



Geometric Approach

- Removing a Non-centroid
  - Update objective function
  - Revert assignment
  - Smaller or equal coverage value



Algorithm Comparison

- Complexity of operations

Algorithm	Insert		Remove	
	Centroid	Non-Centroid	Centroid	Non-Centroid
Naïve BB	$\Theta(N)$	$\Theta(K)$	$\Theta(N)$	$\mathcal{O}(1)$
Geometric BB Average Case [1]	$\mathcal{O}(\log K + N/K)$	$\mathcal{O}(\sqrt{K})$	$\mathcal{O}(N/K)$	$\mathcal{O}(1)$
Geometric BB Worst Case	$\mathcal{O}(K + N)$	$\mathcal{O}(K)$	$\mathcal{O}(N)$	$\mathcal{O}(1)$

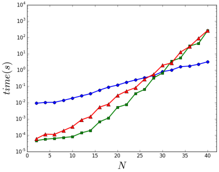
[1] to be shown

Algorithm Comparison

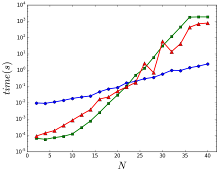
- Tests Performed
  - Effect of N
    - Change N
    - Keep proportional K
  - Effect of K
    - Fixed N
    - Change K

Algorithm Comparison

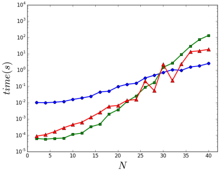
Effect of N



(a) $K = 0.25N$



(b) $K = 0.5N$

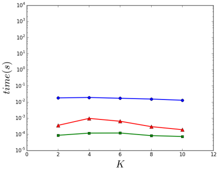


(c) $K = 0.75N$

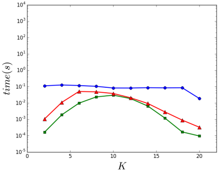
● – Integer Linear Programming ▲ – Delaunay Assisted B&B ■ – Naive B&B

Algorithm Comparison

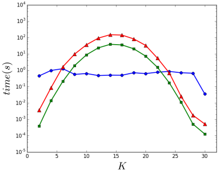
Effect of K



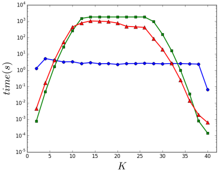
(a) $N = 10$



(b) $N = 20$



(c) $N = 30$



(d) $N = 40$

● – Integer Linear Programming ▲ – Delaunay Assisted B&B ■ – Naive B&B

Future Work

- Heuristic Approach
- Approximation Algorithms
- Adapt to allow panning and zooming
- Integration with WFS standard
- Benchmark with real data