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Faculty of Environmental Sciences, Department of Geosciences, **Institute for Cartography**

Master thesis:

Derivation of continuous zoomable road network maps through utilization of "*Space-Scale-Cube*"

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First Things First…

Breaking down the name:

- Road network maps
- Continuous zooming / vario-scale
- Space-Scale-Cube

Terminology and Abbreviations:

- Point / Vertex / Node
- Edge / Segment
- tGAP: topological Generalized Area Partitioning
- SSC: Space Scale Cube
- LoD: Level of Detail

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Presentation Agenda

- Problem Definition
- Generalization
  - Operators
- Vario-scale geoinformation
  - tGAP
  - SSC
- Road Network SSC
  - Theory
  - Implementation
- Conclusions and outlook
- References
- Acknowledgements
- Questions?

Problem Definition

Scale matters...

Longley, Paul, et al. (2012, p.5):

"Scale or level of geographic detail is an essential property of any GIS project."

O'Sullivan, David, and David John Unwin. (2003, p.10):

"Geographic scale is important!"

Problem Definition

Scale matters...

Geographic information is dramatically based on scale:

- Measurements
- Analysis
- Compare
- Combine
- Queries
- Visualization

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Problem Definition

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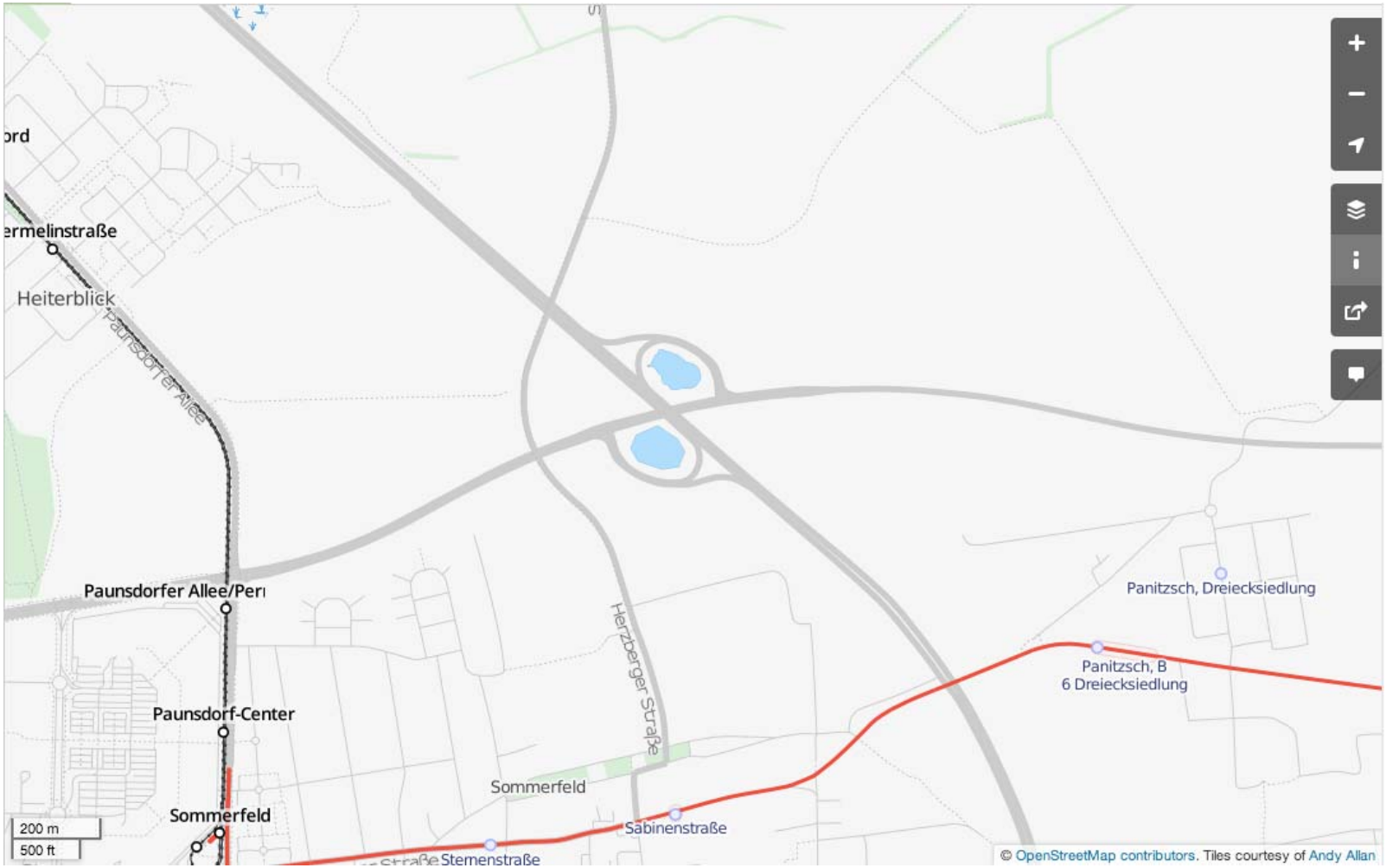

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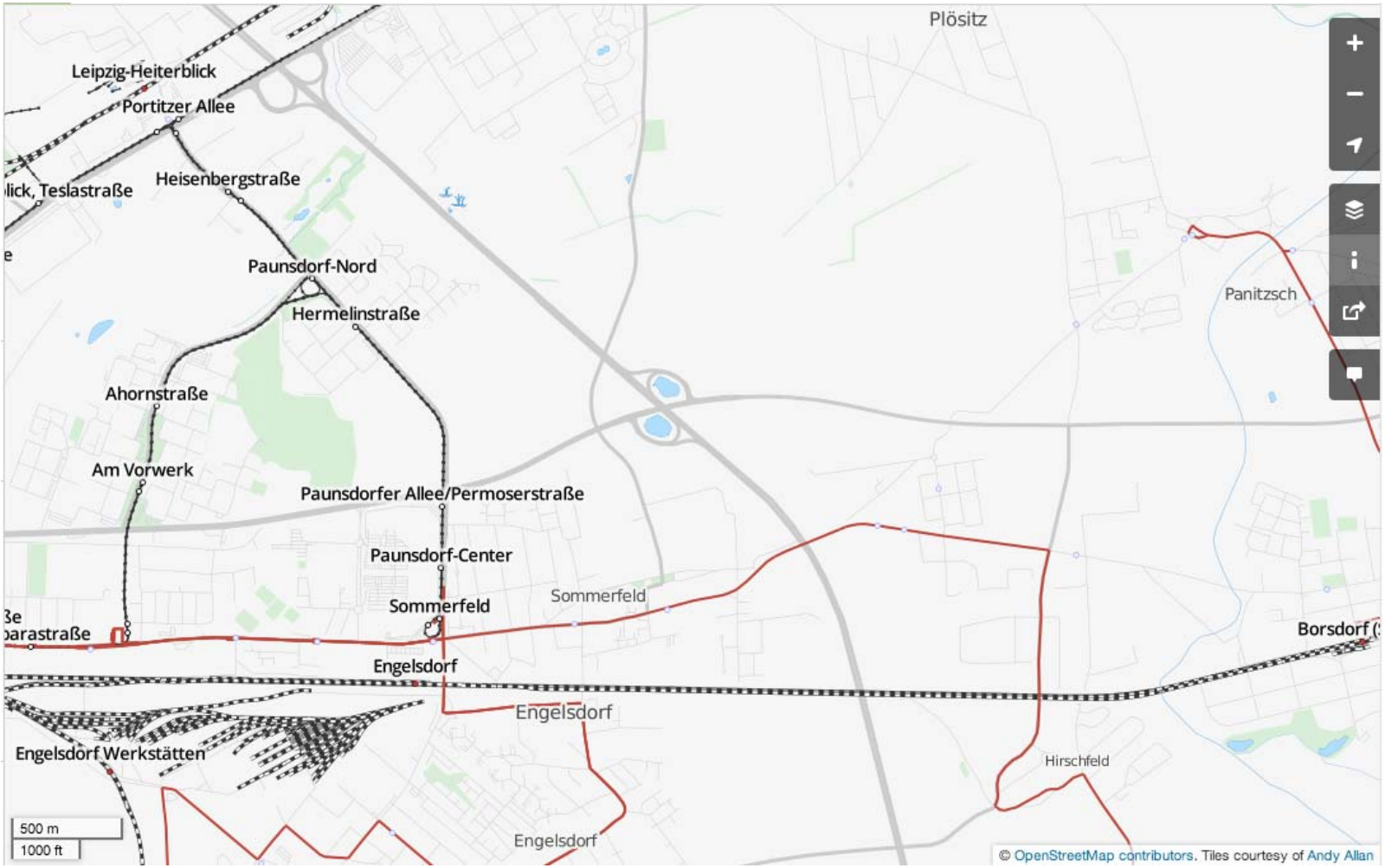
Problem Definition



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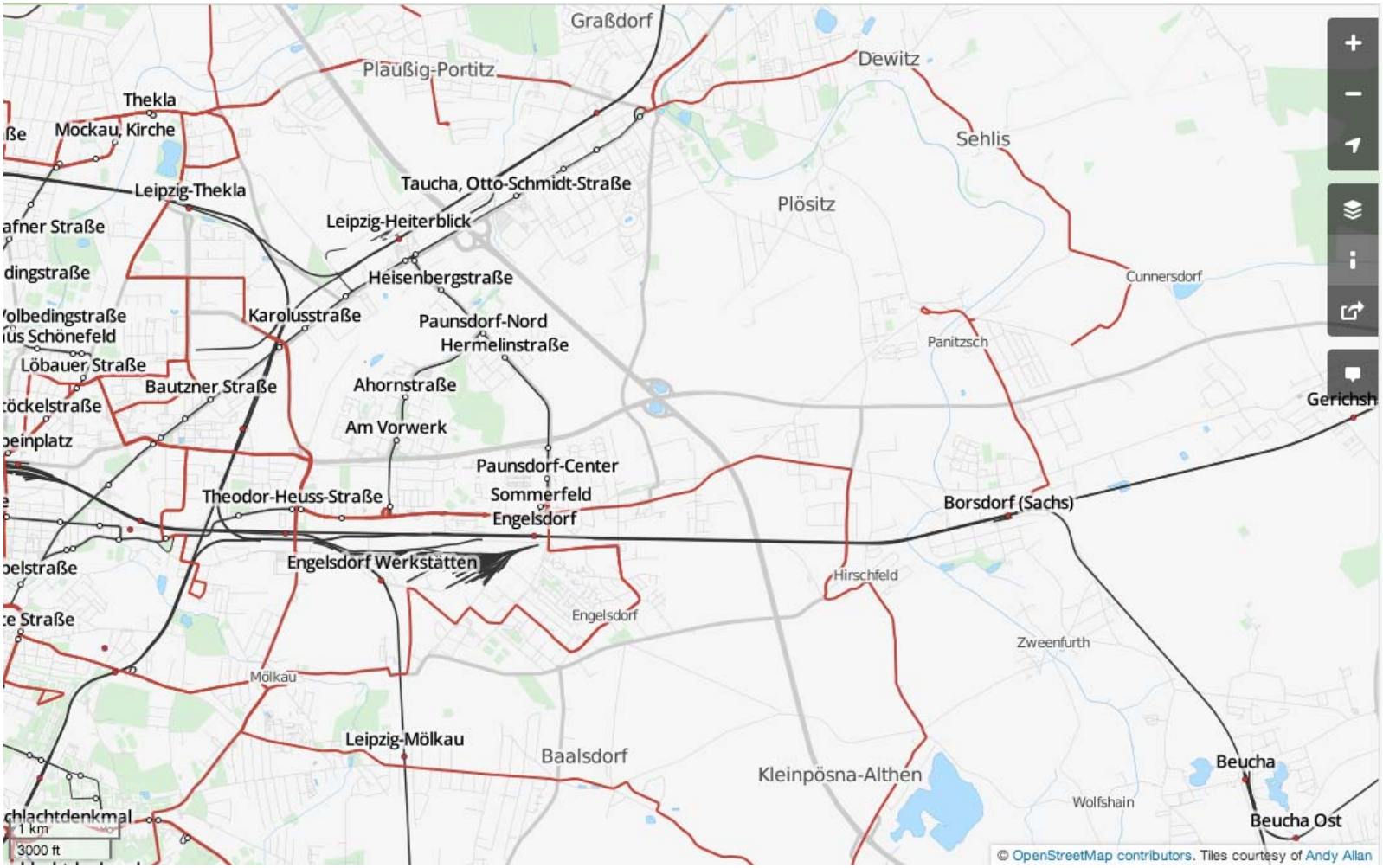
Problem Definition



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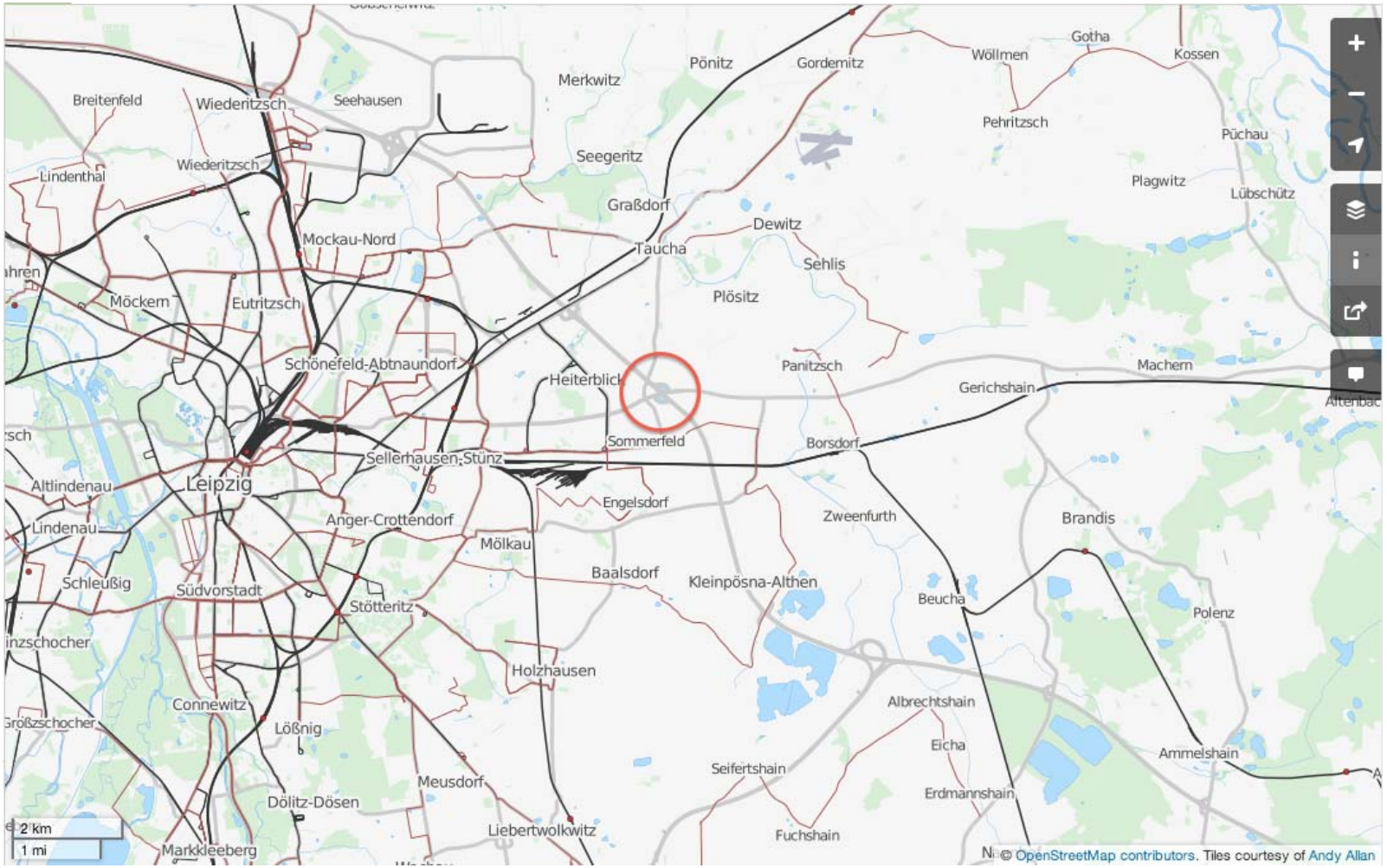
Problem Definition



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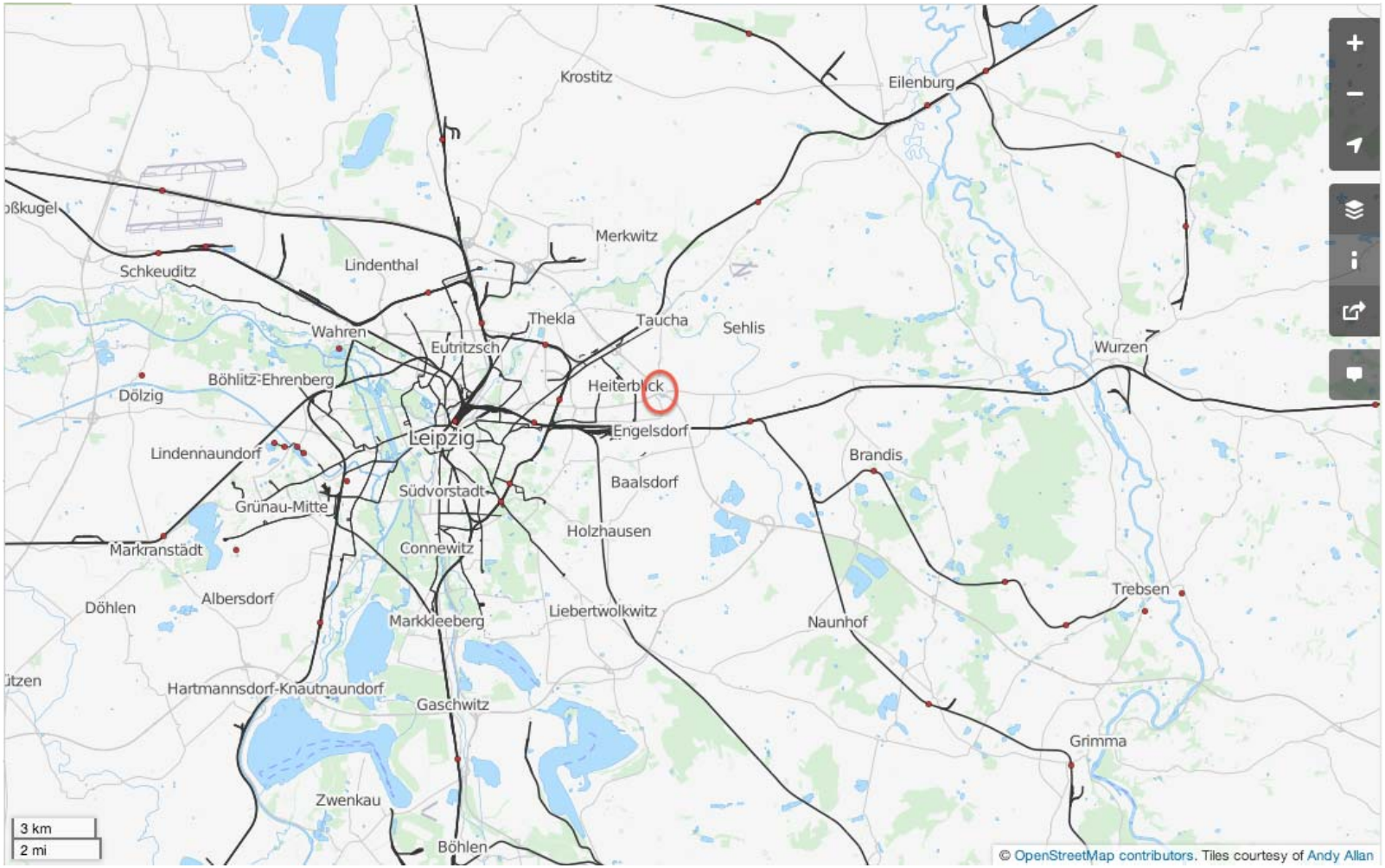
Problem Definition



Problem Definition

We have several (predefined) scales...

- Geographical information is gathered and stored with the highest scale (highest LoD).
- In order to access, query, analyze, **"visualize"** and **"store"** geographic data the scale plays an important role.
- There is always need to have visualization in different (predefined) scales.
- Smaller scale should be derived from larger scales (main activity of Generalization).

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Problem Definition

We have several (predefined) scales...

Some examples from

"**Bundesamt für Kartographie und Geodäsie**"

Product Name	Scale	Product Form
Topographische Übersichtskarte (TÜK200)	1 : 200,000	Paper
Topographische Karte (TK500)	1 : 500,000	Paper
Übersichtskarte (ÜD750)	1 : 750,000	Paper
Digitale Topographische Karte Vorläufige Ausgabe (DTK25-V)	1 : 25,000	Digital
Digitale Topographische Karte Vorläufige Ausgabe (DTK100-V)	1 : 100,000	Digital

Data from: http://www.bkg.bund.de/nn_159198/DE/Bundesamt/Produkte/Produkte_node.html__nnn=true

Problem Definition

Can we produce geodata with any arbitrary scale?

- Theorize, formulize, model, evaluate and formalize the process of derivation of **"arbitrary scale"** derivation of geoinformation.
- Who is interested?
  - Scientists
  - Cartographers
  - National Mapping Agencies (NMAs)
  - GIS software vendors
  - Web maps services
  - **Users**

Problem Definition

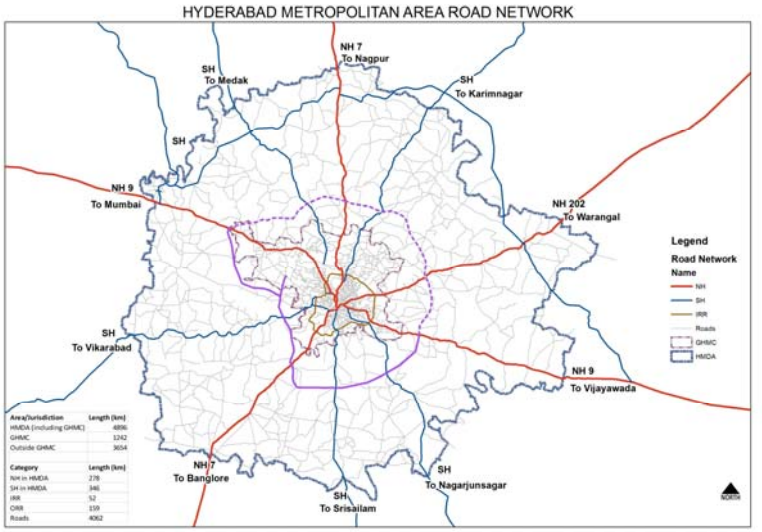
Can we produce geodata with any arbitrary scale?

- There have been several research efforts to achieve this goal. Space-Scale-Cube (Meijers and Van Oosterom 2011) is amongst them.
- SSC considers building up tree hierarchical structure on polygon (area) features.
- Hierarchical data structure enables the system to prioritize features.
- Arbitrary scale query leads to selection of features based on hierarchy. Selected features will be visualized.
- Features will go through geometrical smoothing (compatible with the scale query).

Problem Definition

Why networks are different?

- Geometrical dimension is different.
- Different topology (neighborhood, distance and etc.)
- Connectivity modeling is different.
- Flow / movement modeling can be done in networks.



Problem Definition

Is it possible to combine these two concepts?

- The solution is "Road Network SSC"!
- The solution should cover:
  - Feasibility study of adapting SSC to accept road network data.
  - Development of appropriate hierarchical data model.
  - Development of smoothing strategy.

Generalization

Cartographic Generalization is...

- Definitions
  - **ICA (1973):** Generalization is the selection and simplified representation of detail appropriate to the scale and/or purpose of a map.
  - **Töpfer and Pillewizer (1966):** Generalization covers process of selection and simplification and the reason is the physical constraints of the map (the size), which limits the amount of objects to be shown at a certain scale of interest.

Generalization

Cartographic Generalization is...

- Definitions (cont.)
  - **McMaster and Shea (1992):** itis defined by answering 3 philosophical questions:
    - Why: Consideration of the objectives of process.
    - When: Carto-metric evaluations for input and outputs of the process.
    - How: Selection of the transformation of data from greater scale to smaller scale (spatial and attributes).
  - **Raisz (1962):** Combination, Omission and Simplification of map entities.

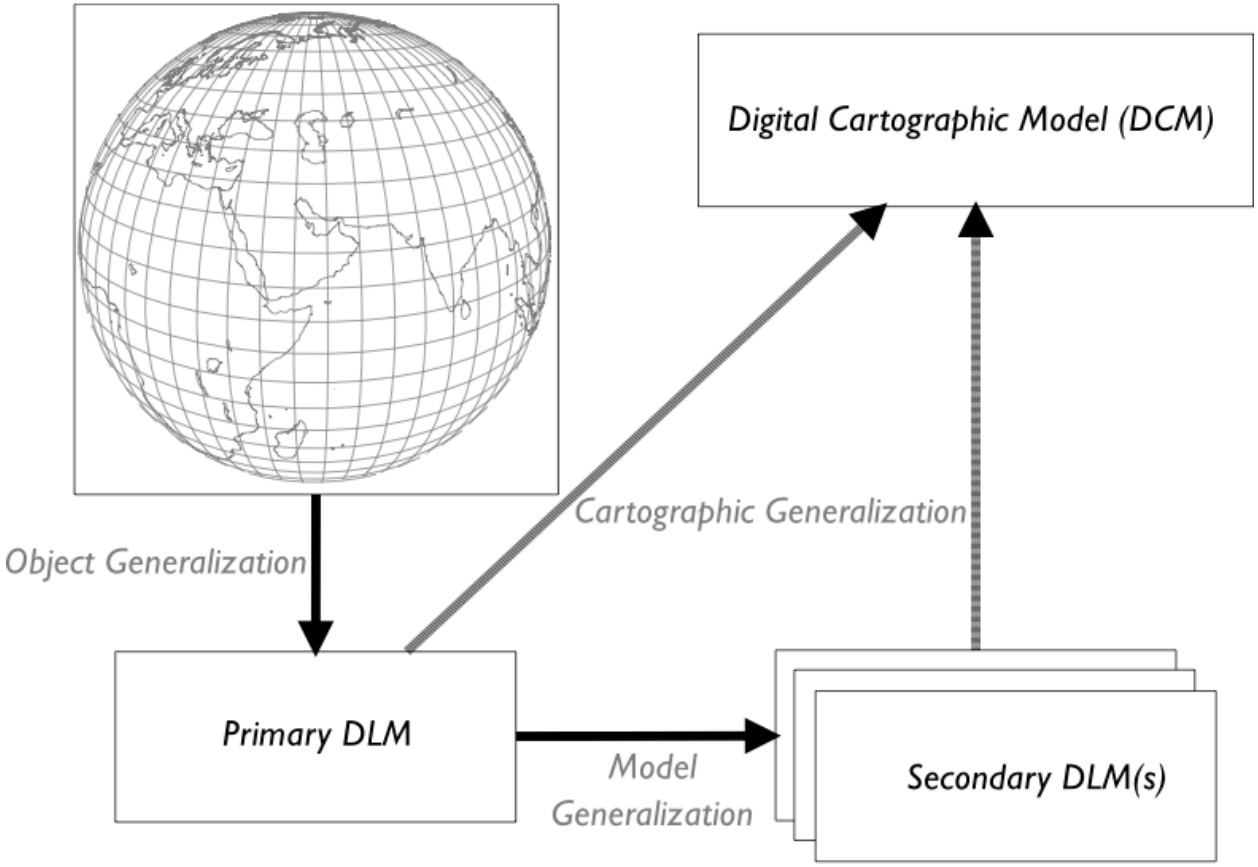
Generalization

Cartographic Generalization is...

- Definitions (cont.)
  - **Robinson, Sale and Morrison (1978):**
    - Elements
      - Simplification
      - Classification
      - Symbolization
      - Induction
    - Controls
      - Objective
      - Scale
      - Graphics limit
      - Quality of data.

Generalization

DLM-DCM Model (after Grünreich 1985)



Generalization

DLM-DCM Model

- This model divides the Generalization process into 3 levels:
  - **Object generalization:** Abstraction with a finite amount of observations and measurements from the objects in reality to a database/model correspondent. This process leads to primary DLM.
  - **Model generalization:** Applying spatial and semantic transformation with a controlling manner in order to result in a set of less features and resulting in reduction of memory and storage usage and leads to secondary DLM.

Generalization

DLM-DCM Model (cont.)

- **Cartographic generalization:** Mainly concerned with improvement of the visual representation of data in form of digital or paper maps. The main role is played by symbolization and the result is a DCM.

Operators

Selection:

Selecting the specific instances of a specific feature type, which should appear in the target data model.
The process is normally done based on a query parameter or an attribute of such instances

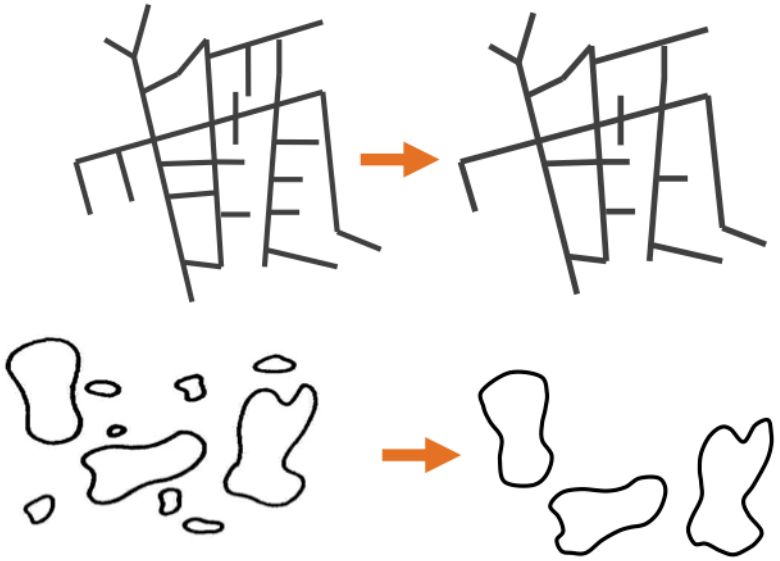


Image from Peters and Meng (2011)

Operators

Simplification:
The process of reducing the geometric complexity of features toward a simpler representation. This is normally done through selection of a subset of the geometry of the original feature.

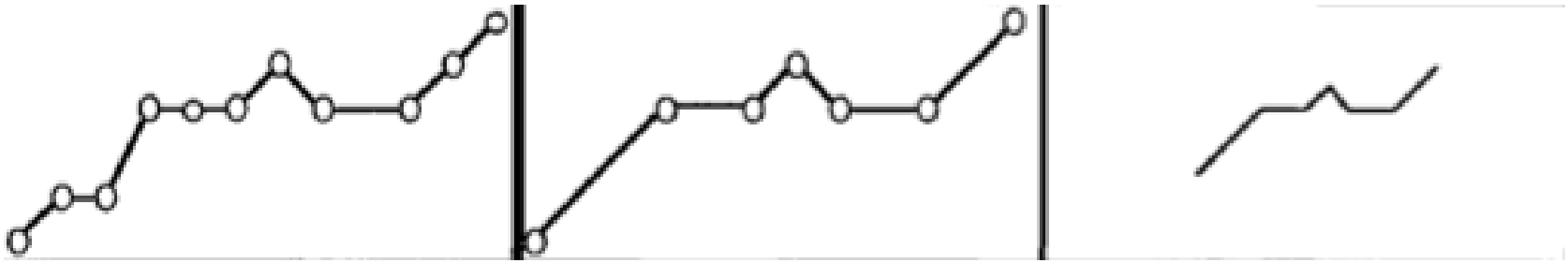


Image from (McMaster and Shea 1992)

Operators

Smoothing:
Capturing more important trends of the lines while dismissing less important trends which would result in less sharp angularity of the geometry.

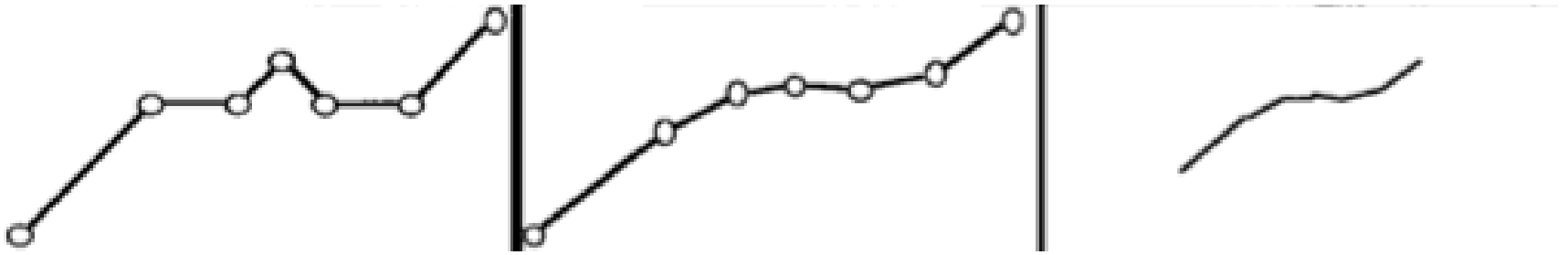


Image from (McMaster and Shea 1992)

Operators

Amalgamation:

Amalgamating a set of spatially adjacent/close geometries of the same class into a single geometry which leads to higher abstraction.

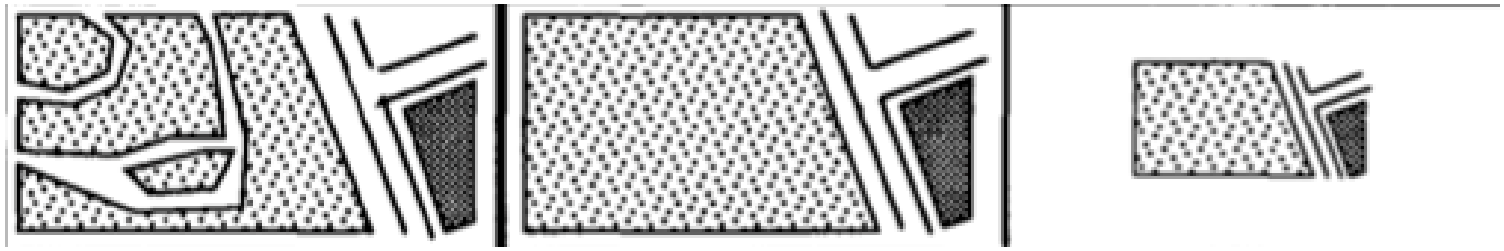


Image from (McMaster and Shea 1992)

Operators

Displacement:
Overcoming complication from proximity, overlap and coincidence by displacing features in order to improve distinguishability.

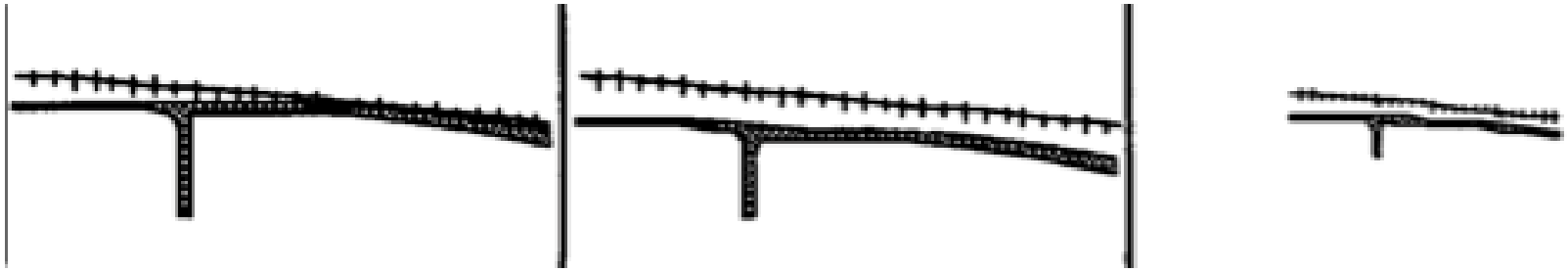


Image from (McMaster and Shea 1992)

Operators

(Dimension) Collapse:
Is the process of reducing the geometrical dimension of the feature to a lower dimension.

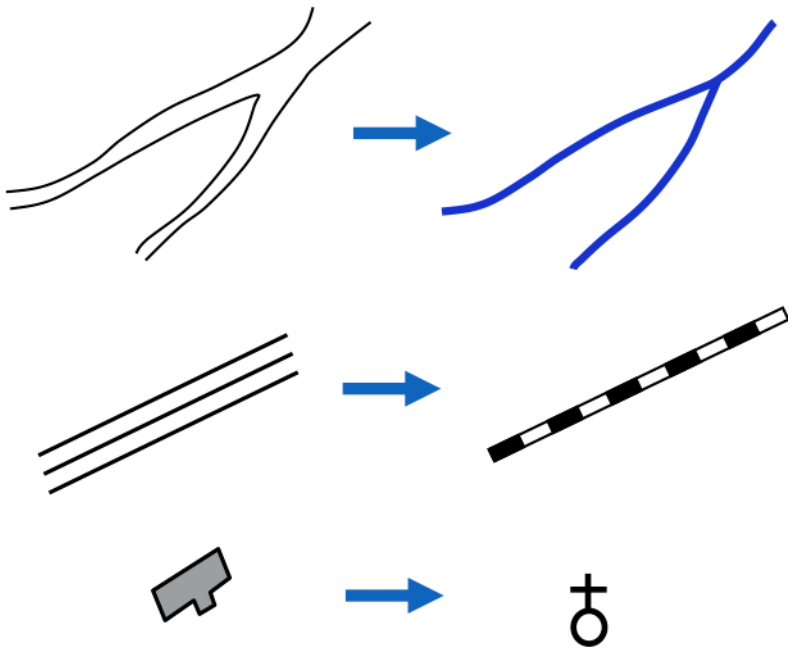


Image from Peters and Meng (2011)

Operators

Classification:
Grouping features who share an identical or similar attribute into categories.

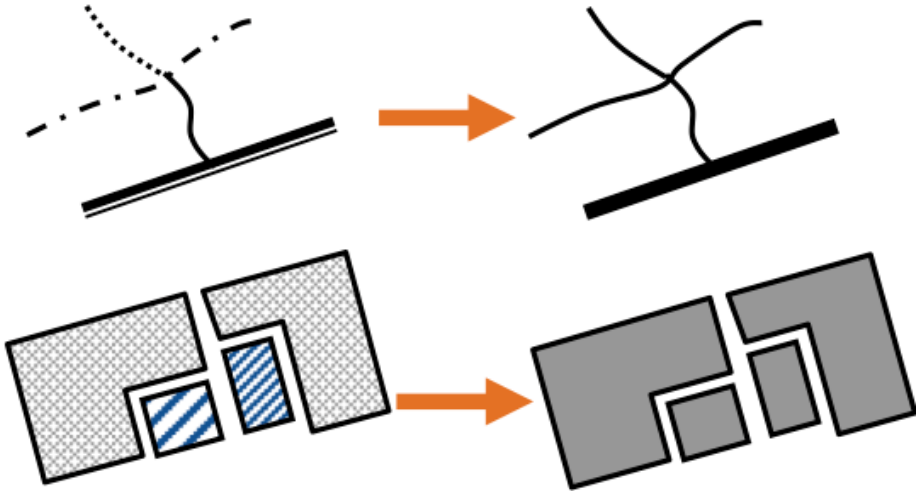


Image from Peters and Meng (2011)

Operators

Exaggeration:

Applying geometric exaggeration on certain features in order to guarantee visibility of certain geometric characteristics of the feature. Normally reducing the scale will affect some visibility detailed criteria of features.

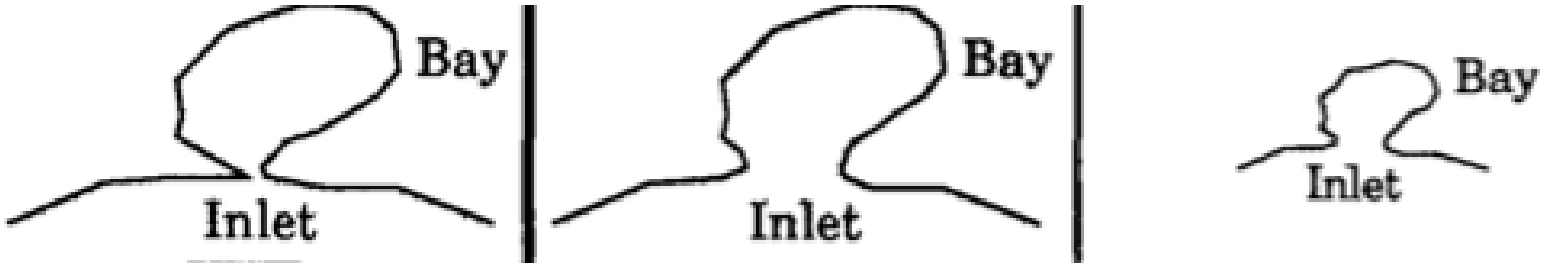


Image from (McMaster and Shea 1992)

Operators

Enhancement:

Modifying certain geometric parts of graphic representation to pro- duce a pleasing view or to emphasize an object in order to fit the requirements of the map.

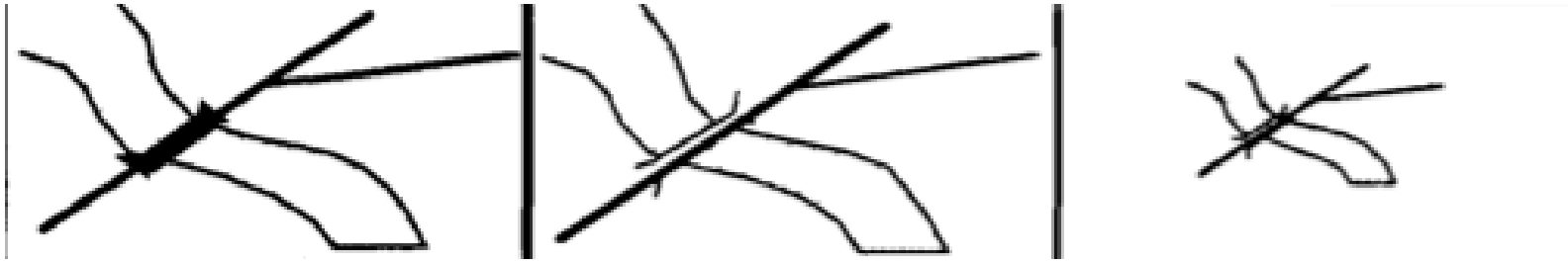


Image from (McMaster and Shea 1992)

Operators

Merge:

Merging features to decrease complexity and individual features number and preserve the remnant. Generalized feature represents the merged features.

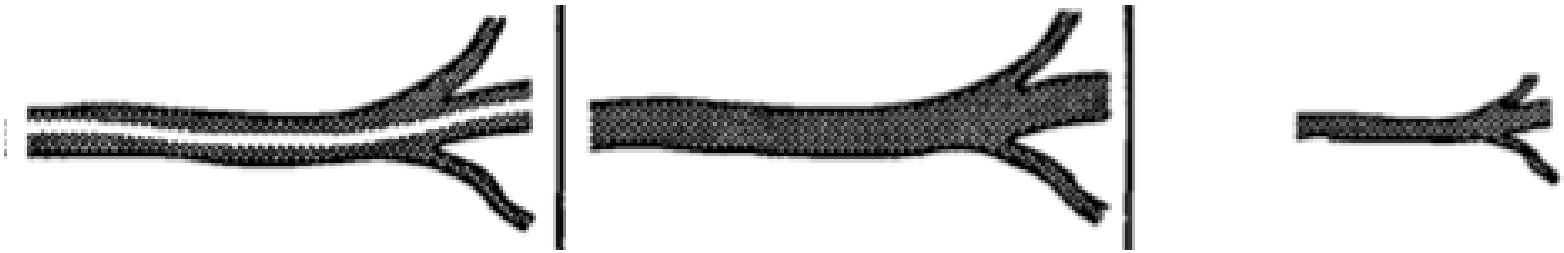


Image from (McMaster and Shea 1992)

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Vario-scale Geoinformation

Arbitrary scale geoinformation visualization efforts...

Different terms:

- **Scaleless database** as in Van Oosterom (1991).
- **On-the-fly generalization** as in:
  - Van Oosterom (1995)
  - Burghardt, Purves and Edwardes (2004)
  - Cecconi and Galanda (2002)
- **Continuous generalization / continuous zooming** as in:
  - Van Krevald (2001)
  - Sester and Brenner (2005)

Vario-scale Geoinformation

Arbitrary scale geoinformation visualization efforts...

Different terms (cont.):

- **Vario-scale** or **variable scale geoinformation** as in:
- Meijers and van Oosterom (2011)
- Meijers (2006)
- Van Oosterom (2005)

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Vario-scale Geoinformation

Arbitrary scale geoinformation efforts...

Vario-scale geoinformation and cartography generally needs two components/solutions:

- A data storage in which geographical information is stored only once. Such model should solve redundancy problems.
- A solution to visualize contents in any arbitrary scale (inter-LoDs). This will help the system to derive a valid visualization of geographic features responding to any scale query.

tGAP

- topological Generalized Area Partitioning, introduced by Van Oosterom (2005).
- tGAP is a hierarchical data structure. This data structure stores the relationships between area features. It is composed of:
  - A face tree
  - Multitude of edge trees (forest)
- Formation is an iterative process, in each step:
  - Least important feature is identified and dissolved in its appropriate neighbor. Importance evaluation is based on (Area*Class-Weight).
  - One parent-child relation is added to face tree.
  - Depending on the situation, appropriate action would take place in edge-forest (merge, survive, omit).

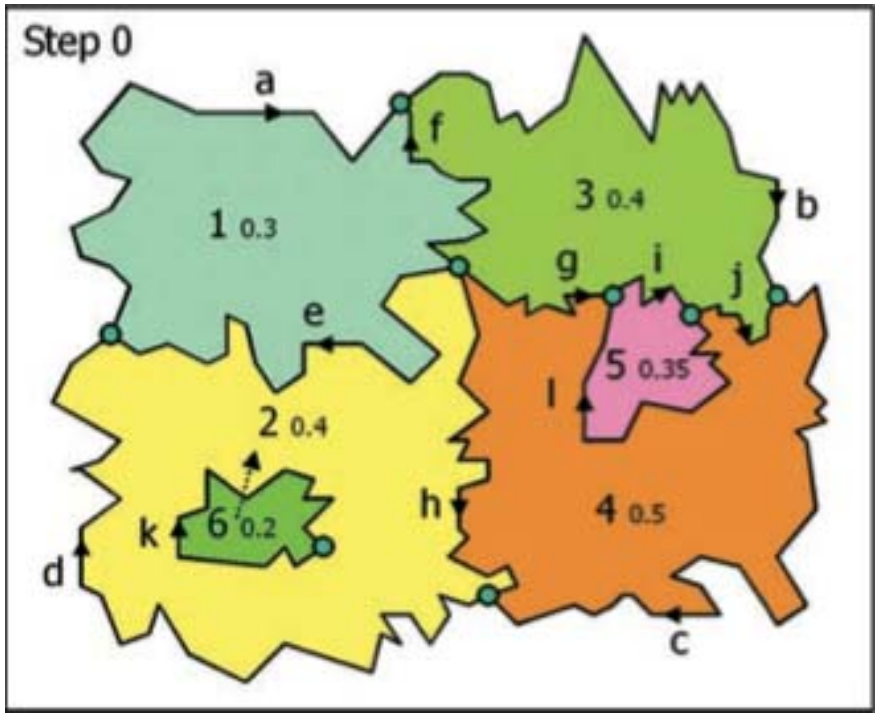
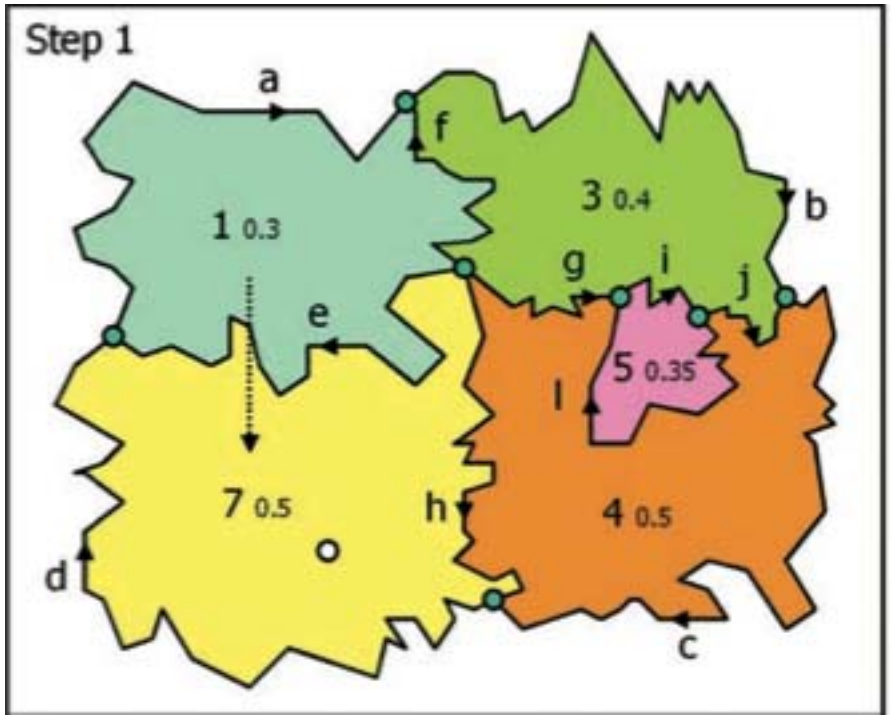


Image from (Van Oosterom 2005)



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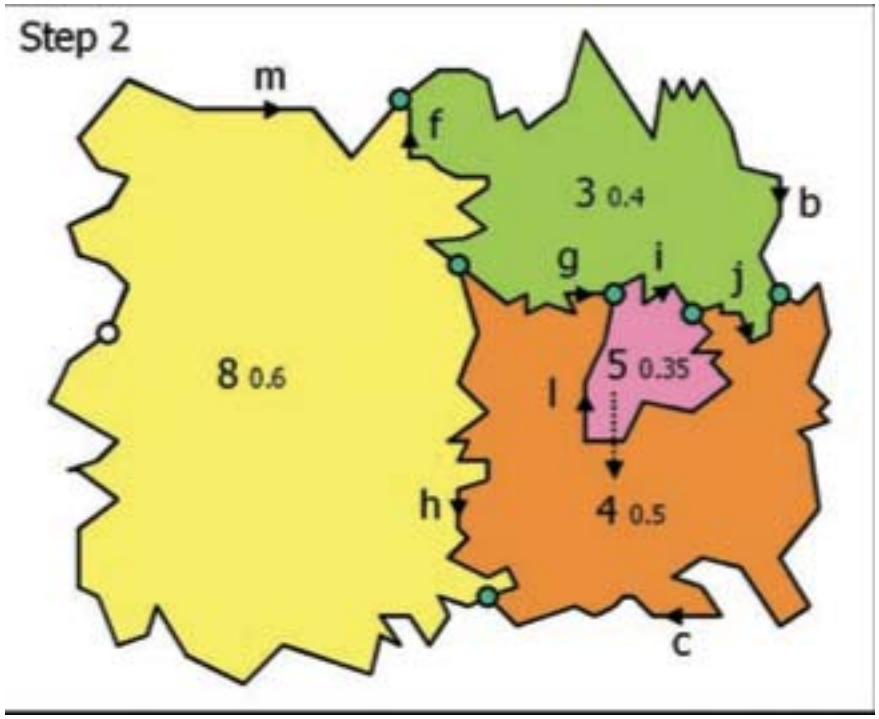

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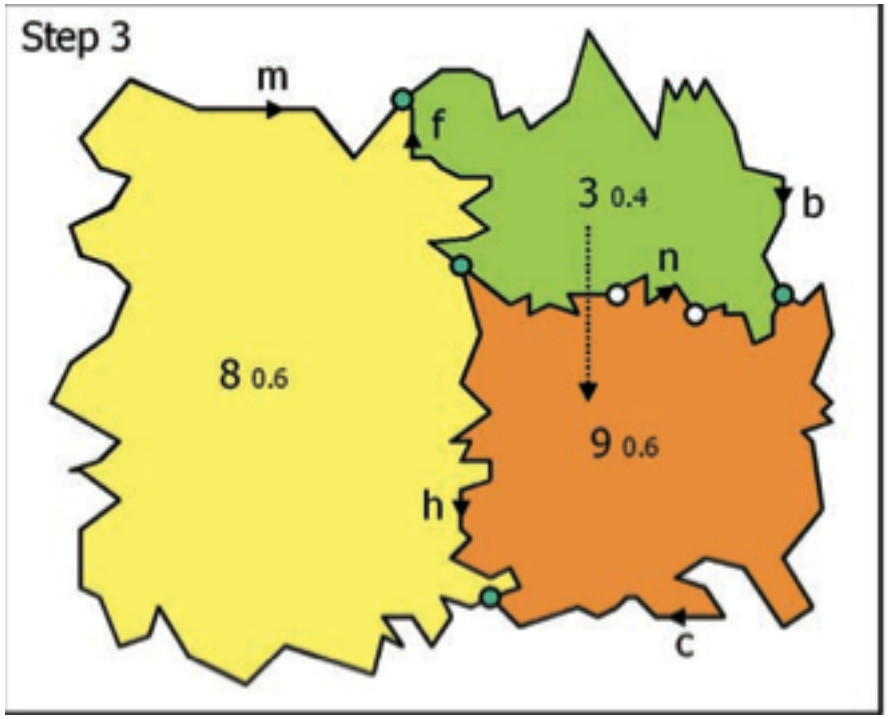

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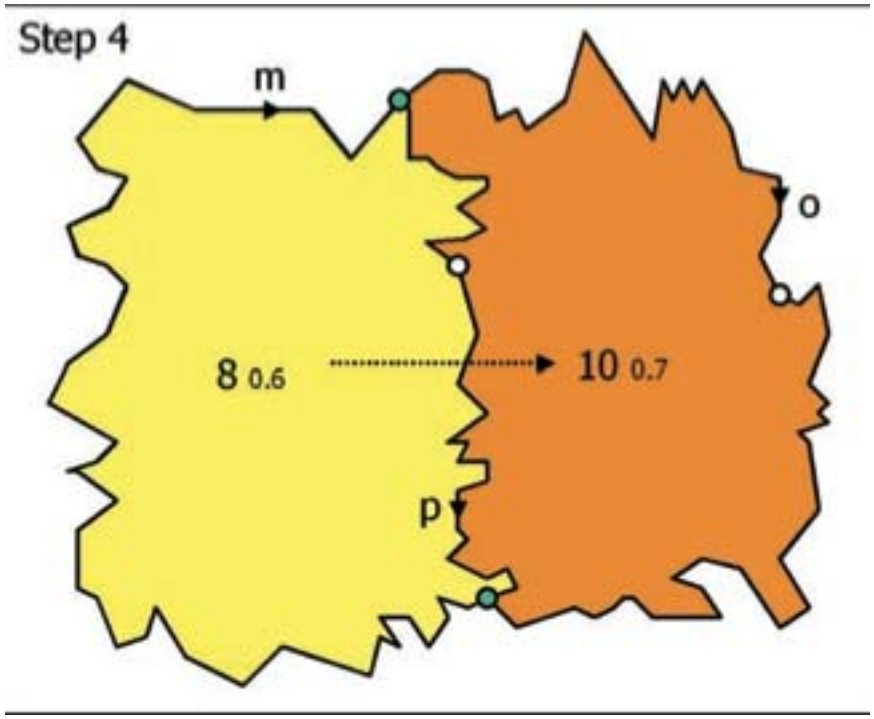

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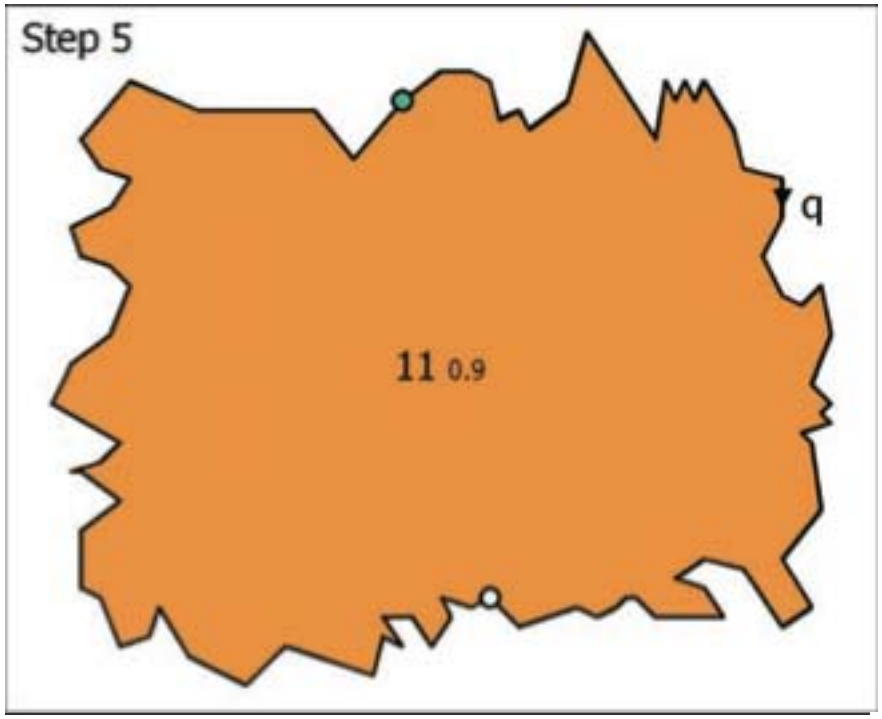
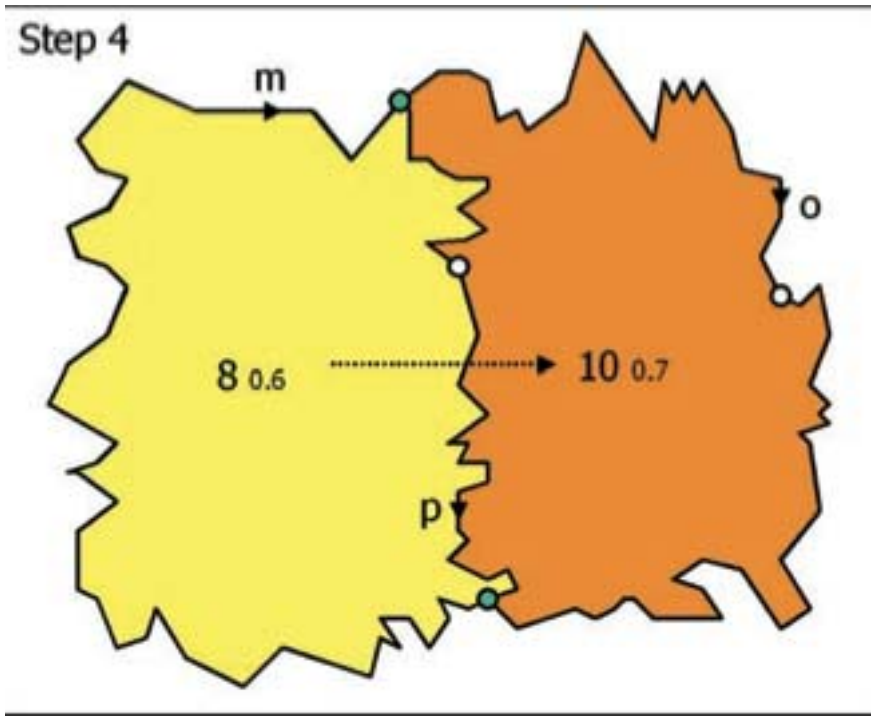


Image from (Van Oosterom 2005)

Face-tree



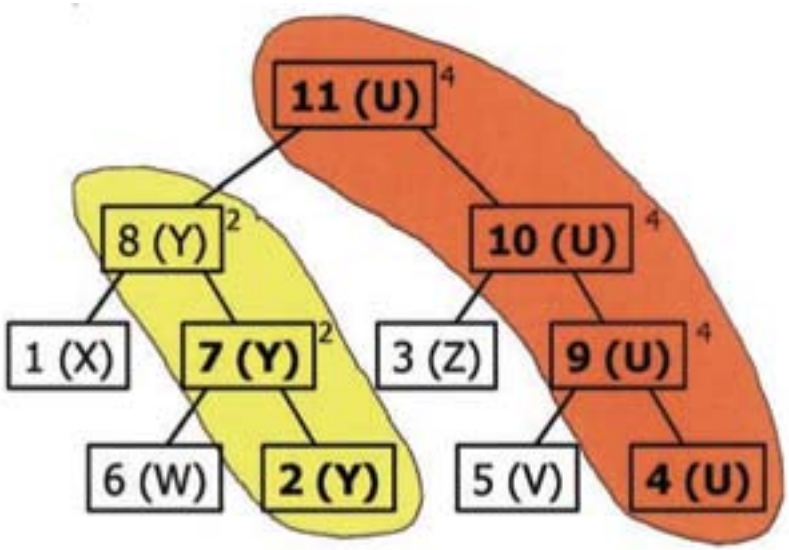


Image from (Van Oosterom 2005)

Edge-Forest (multitude of trees)

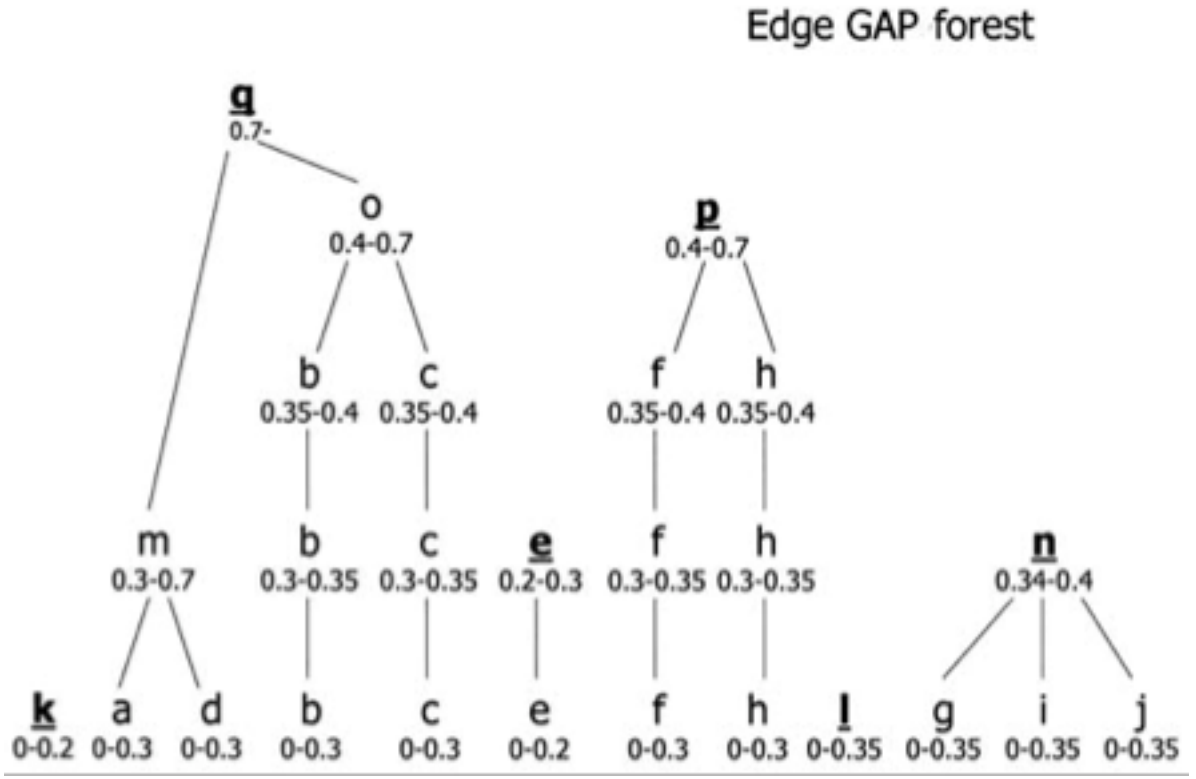
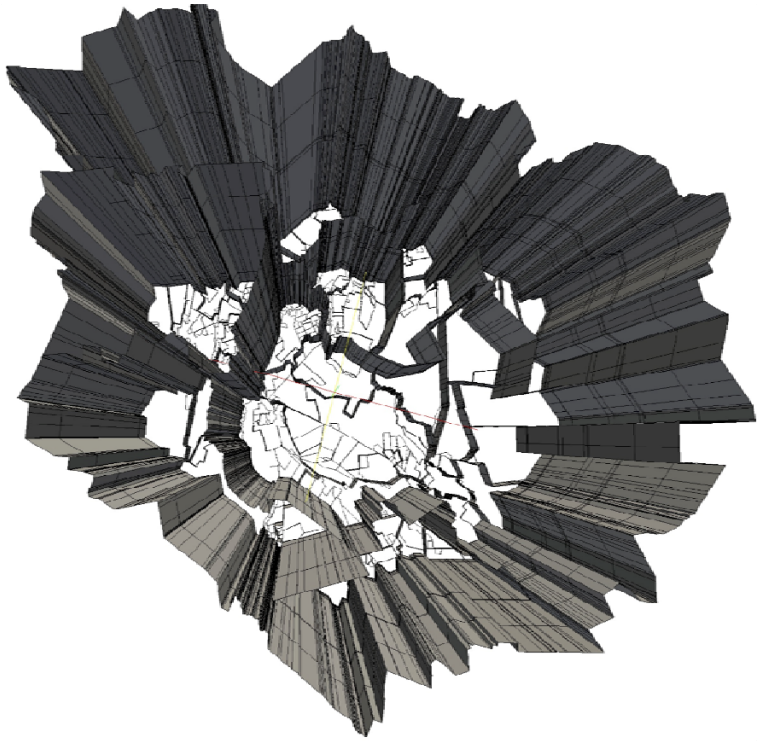


Image from (Van Oosterom 2005)

SSC

- Space Scale Cube, introduced by Meijers and Van Oosterom (2011).
- Basically is smoothing of tGAP in order to support arbitrary scale generalization.
- Geographic information is in ordinary 2D (x,y) and the 3rd dimension is the scale.
- Movements on the 3rd dimension leads to change in scale.
- In order to derive visualization, the intersection of an imaginary plane and 3D imaginary SSC takes place (slicing).



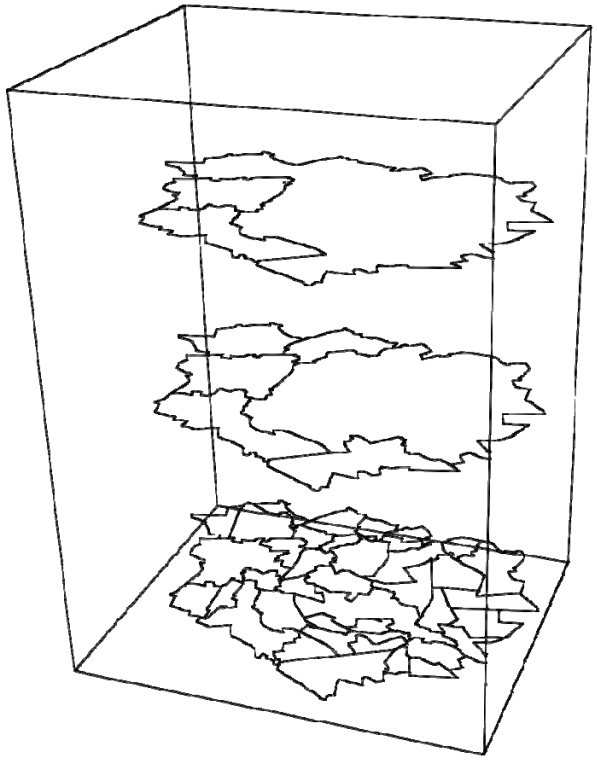
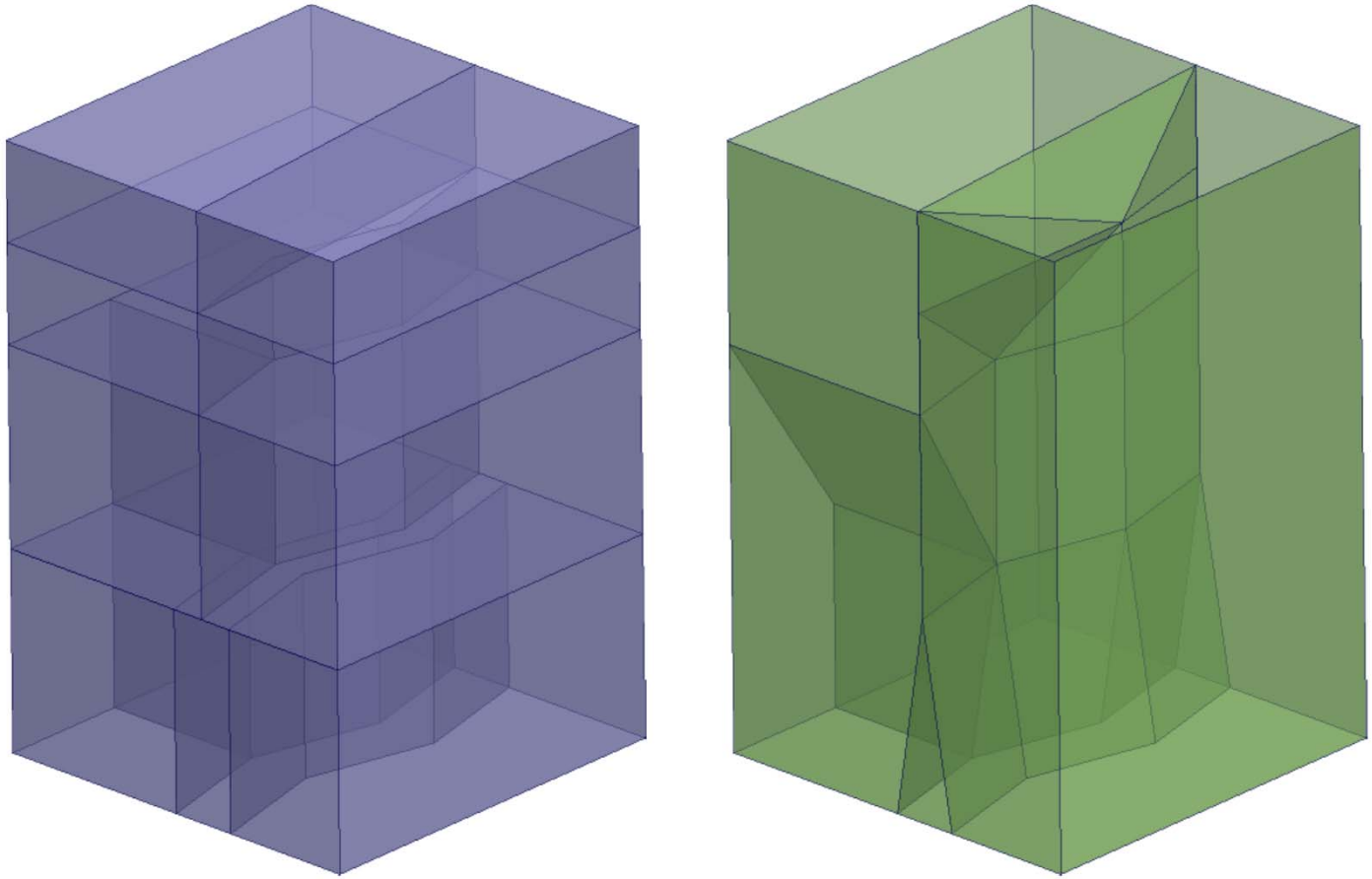


Image from (Van Oosterom and Meijers 2011)



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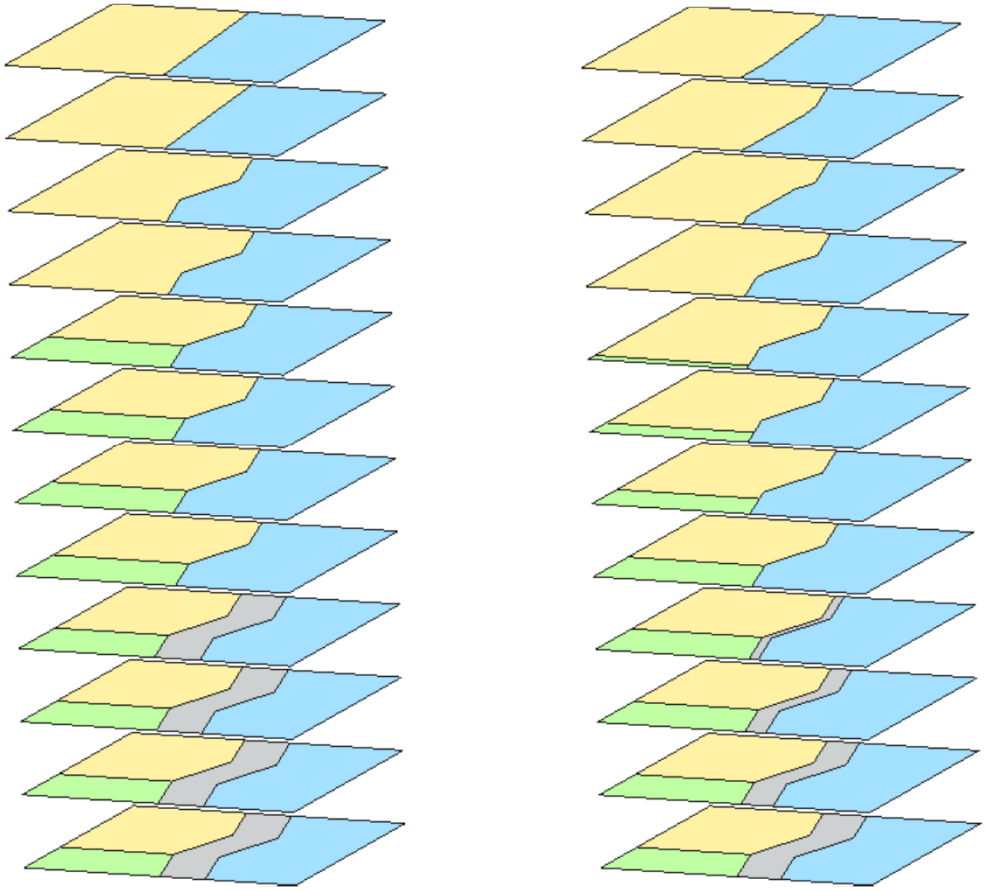


Image from (Van Oosterom and Meijers 2011)

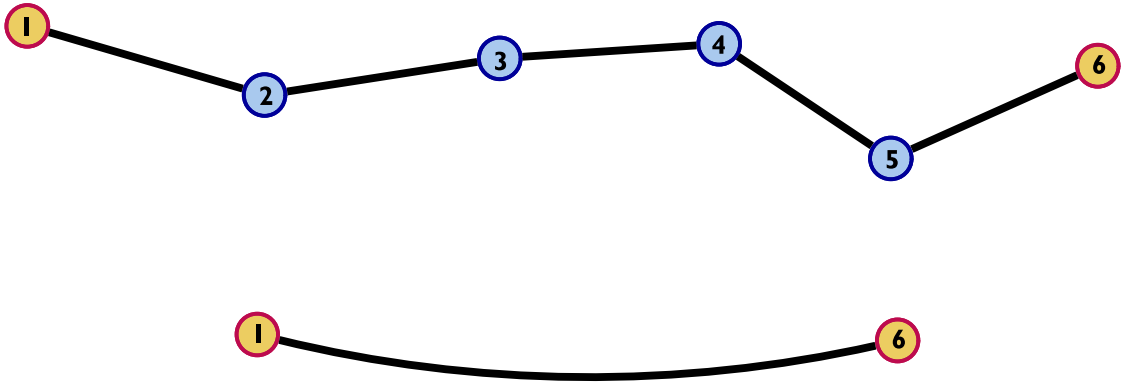
Road Network SSC, Theory

Theorizing the solution, some points...

- Road network data contains geometry (road segments) and topology (connectivity data).
- Being a network, it is impossible to form a single tree to represent all features (as in tGAP face tree).
- There would be a solution to build a hierarchical data model (leading to a multitude of trees = forest).
- In network analysis, generally graph theory is being used to analyze the network properties.
- In order to support the iterative elimination and merge, there is need for a quantity as importance values. Such quantity can be from geometry, topology or semantic of features. It should be re-calculable.

Road Network SSC, Theory

How the network is being modeled?



Considering situations of having geometry and connectivity.
In each case, data modeling is different.

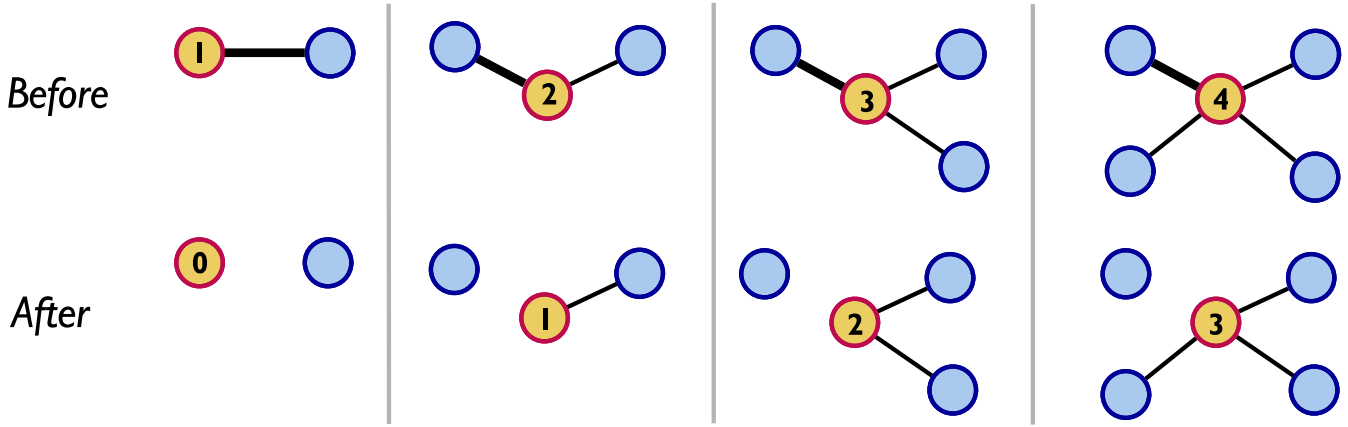
Road Network SSC, Theory

Important or not important? Decision!

- Based on the nature of road networks, there is need to perform feature elimination with regard to connectivity issues:
  - The network should stay connected.
  - Important features should survive.
  - Hierarchy should be formed.
- The solution is to eliminate features ordered by importance (ordered ascending).
- Eliminating segments also decreases importance of nodes. Nodes can also be eliminated.
- In appropriate situations, merging may happen (and thus forming hierarchy). Decisions are based on node degree.

Road Network SSC, Theory

Important or not important? Decision!

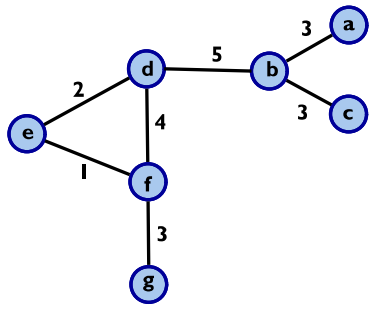
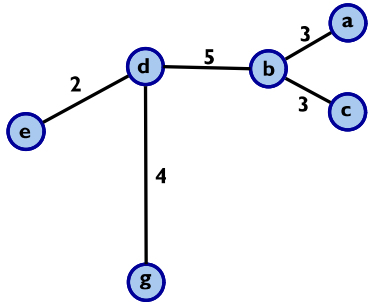
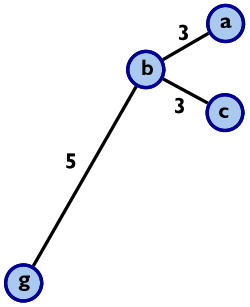
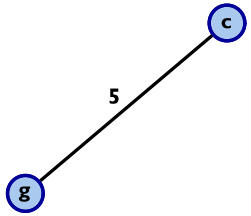
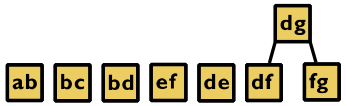
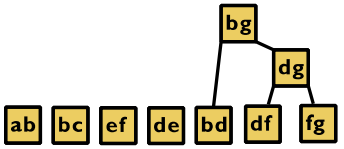
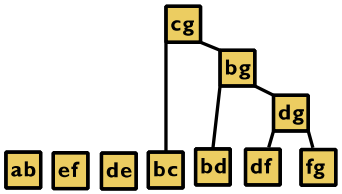


Considering different cases of node degree (valence), before and after edge elimination.

The case of having node degree 2 after the edge elimination is of our interest. It is possible to add a new edge representing the two edges and remove the node and both edges. The new edge will be the parent of the eliminated edges.

Road Network SSC, Theory

How does the algorithm work?

Network (graph)				
Edge Forest				
Decision	remove ef remove fg remove df remove f add dg set_parent fg -> dg set_parent df -> dg	remove de remove dg remove bd remove d add bg set_parent dg -> bg set_parent bd -> bg	remove ab remove bc remove bg remove b add cg set_parent bc -> cg set_parent bg -> cg	

Road Network SSC, Theory

After formation of the data structure...

- The suggested algorithm leads to an edge forest which can be queried to derive appropriate visualization corresponding to the query parameter.
- Similar to SSC, simplification of features can be done with a line simplification algorithm (e.g. Douglas-Peucker).
- There should be a strategy to perform smoothing between LoDs. This strategy should be compliant with the operators used.

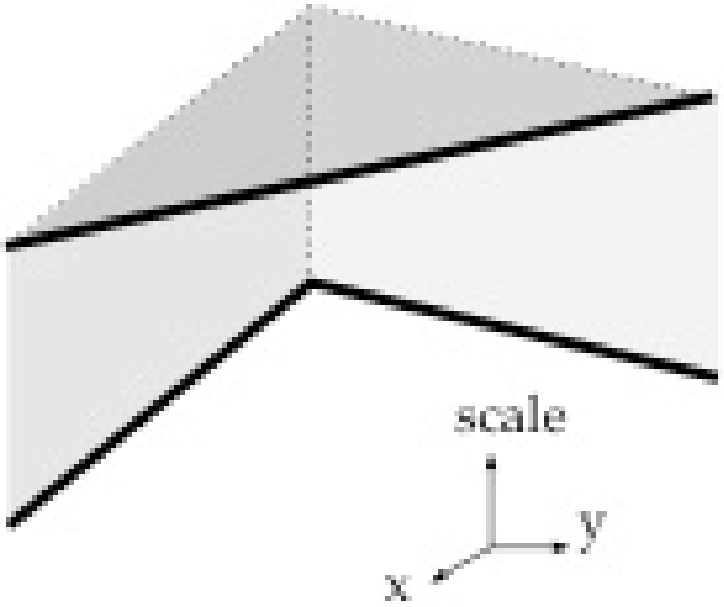
Road Network SSC, Theory

Line simplification in a 3D setup...

- The algorithm eliminates nodes (based on an order from simplification algorithm).
- By eliminating one node, a new LoD is made.
- There is need to smoothen the transition between two LoDs.
- A straight-forward solution is to use set of triangles who replace the change with a geometrical interpolate-able setup.
- In case of non-planar slices, the algorithm gives an appropriate solution.

Road Network SSC, Theory

Line simplification in a 3D setup...



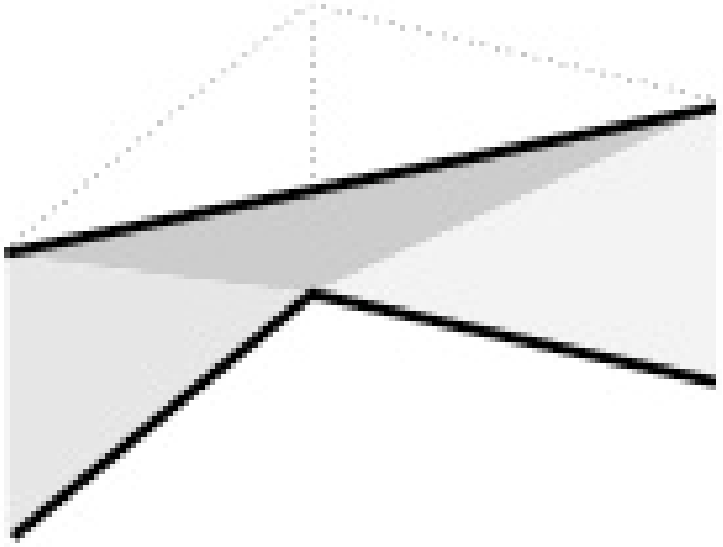
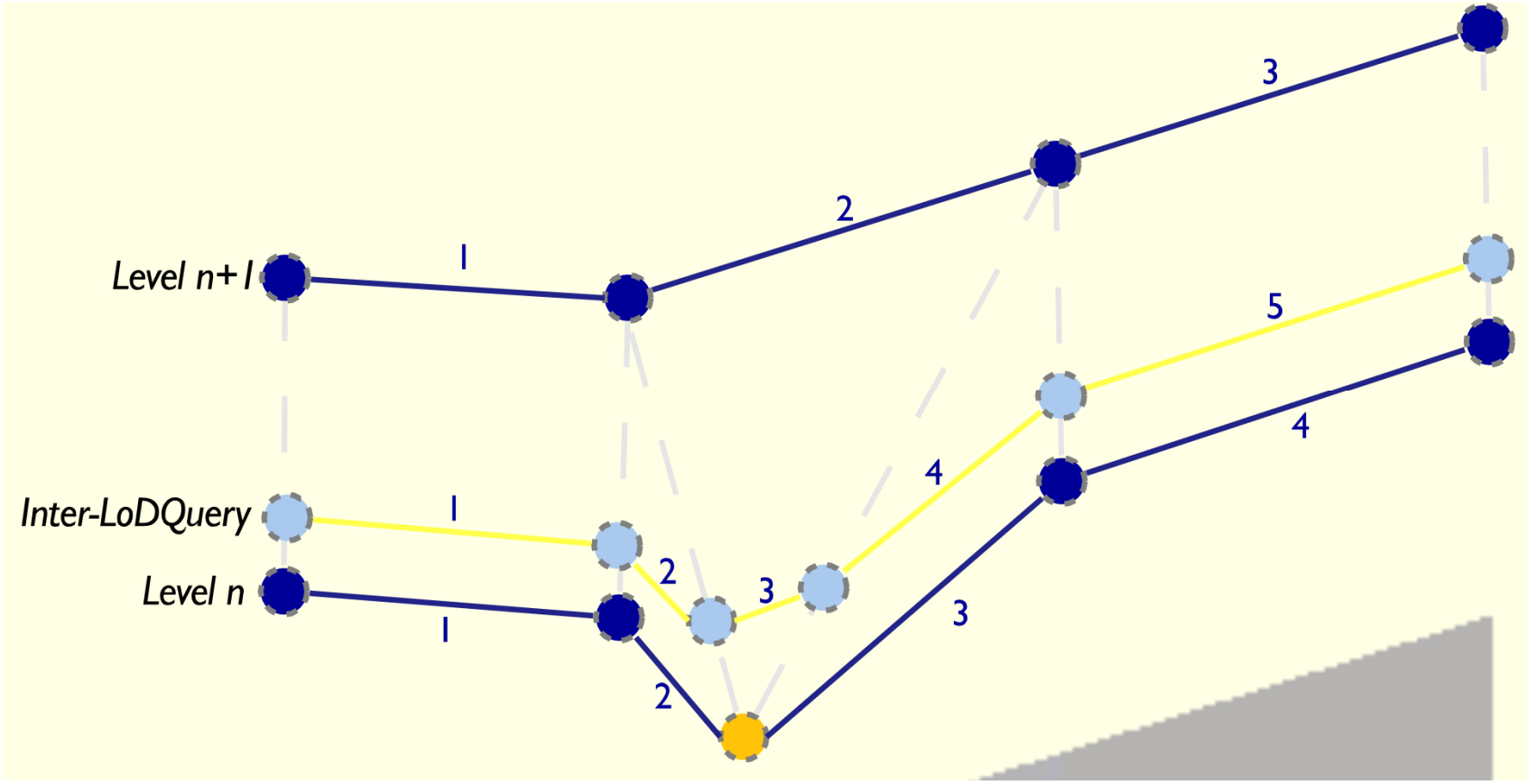


Image from (Van Oosterom and Meijers 2011)

Road Network SSC, Theory

Line simplification in a 3D setup...



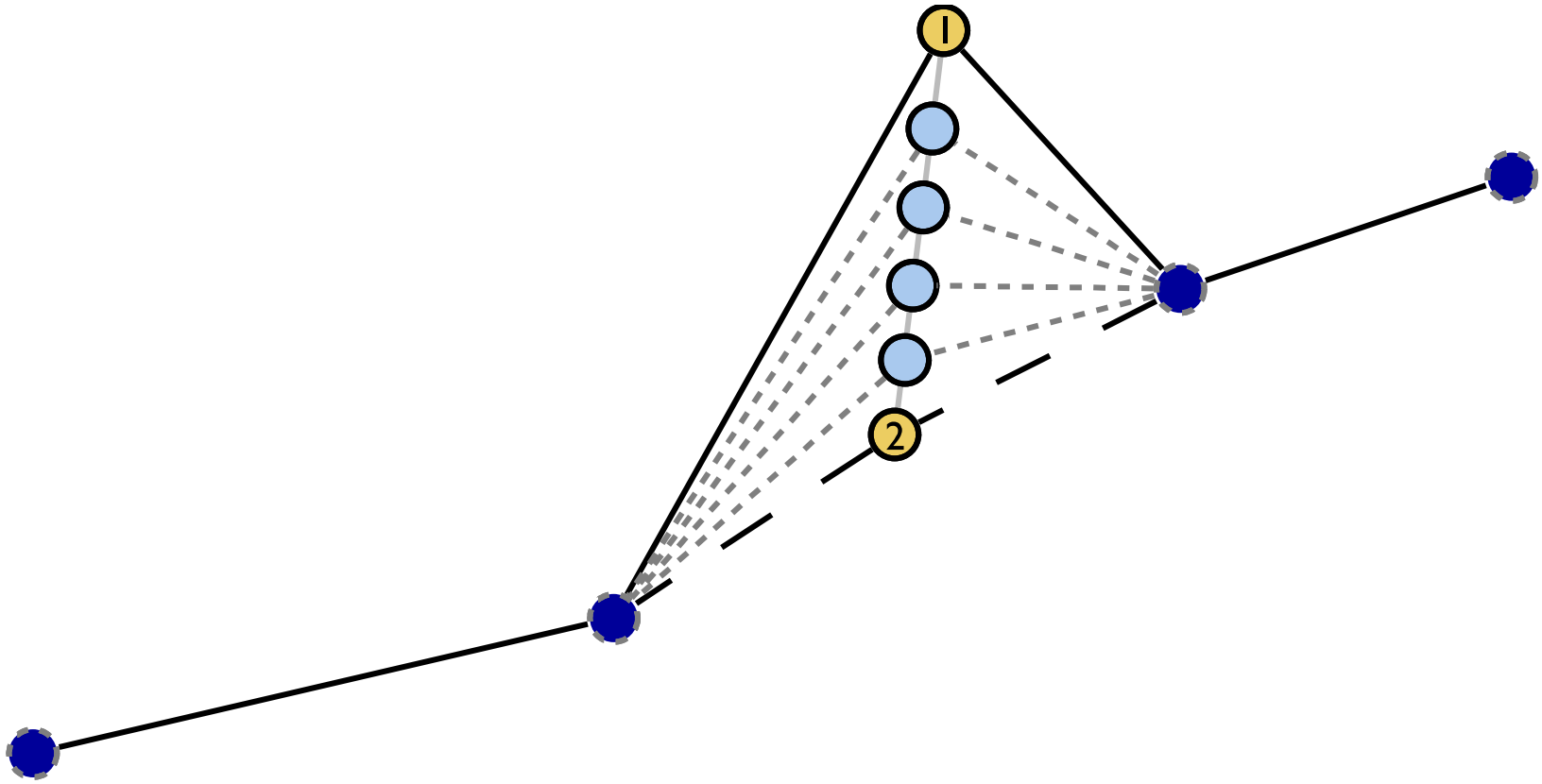
Road Network SSC, Theory

Line simplification in a Pseudo-3D setup...

- The Pseudo-3D solution is an alternative to the 3D solution.
- The smoothing uses the node order of line simplification algorithm.
- In order to answer inter-LoD queries, the elimination candidate node is displaced to the direction of mid-point of its neighboring nodes.
- Simplifies and smoothen the line geometry.
- In case of non-planar slices, the algorithm may give an appropriate solution.

Road Network SSC, Theory

Line simplification in a Pseudo-3D setup...



Road Network SSC, Theory

How to derive a map out of it?

- After the formation of the data structure, it will be query-ready.
- In order to query the data structure, there is need to have an importance value as the query parameter.
- By having the query parameter, forest is being searched. Every tree would be traversed to find the feature who complies with the query.
- The result set is being fetched and visualized.

Road Network SSC, Theory

Discussion on scale...

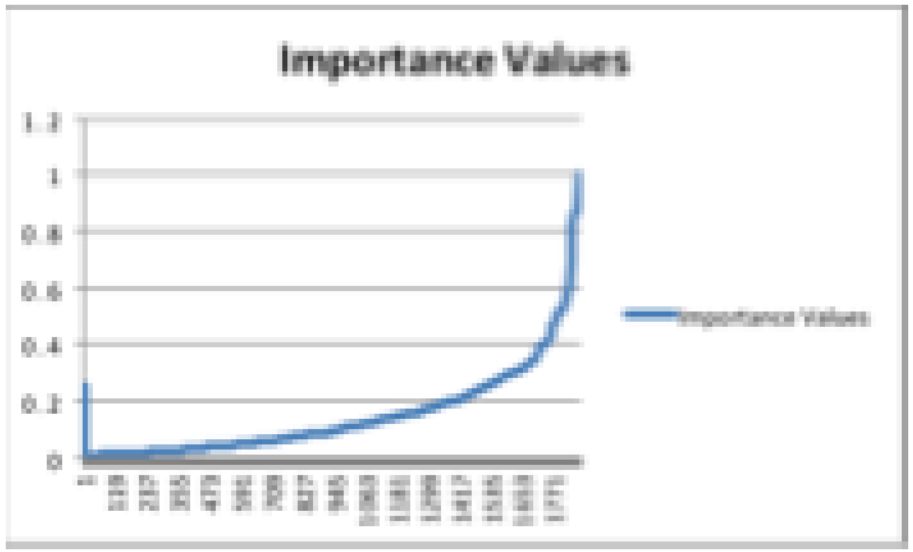
$$n_f = n_a \cdot \sqrt{\frac{M_a}{M_f}}$$

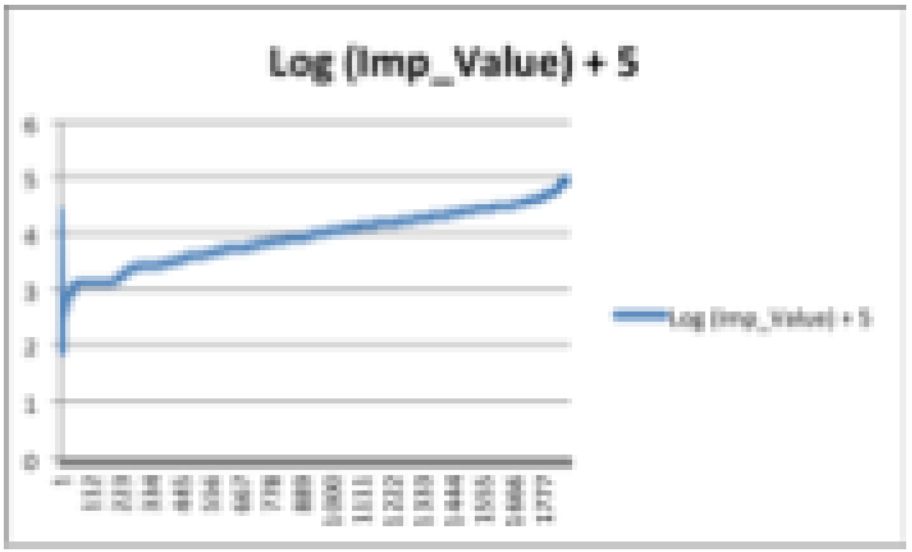
- Radical law of Töpfer describes the relation between number of features on the map the its scale.
- So in order to define properties of the derived map, 3 quantities should be known. By default the information of the source map is available.
- Two situations are considerable:
  - Having the derived map's scale
  - Having the importance value
- In both cases, there is need to have relation between importance values and number of features on the map.

Radical law of Töpfer from (Töpfer and Pillewizer. (1966))

Road Network SSC, Theory

Discussion on scale...



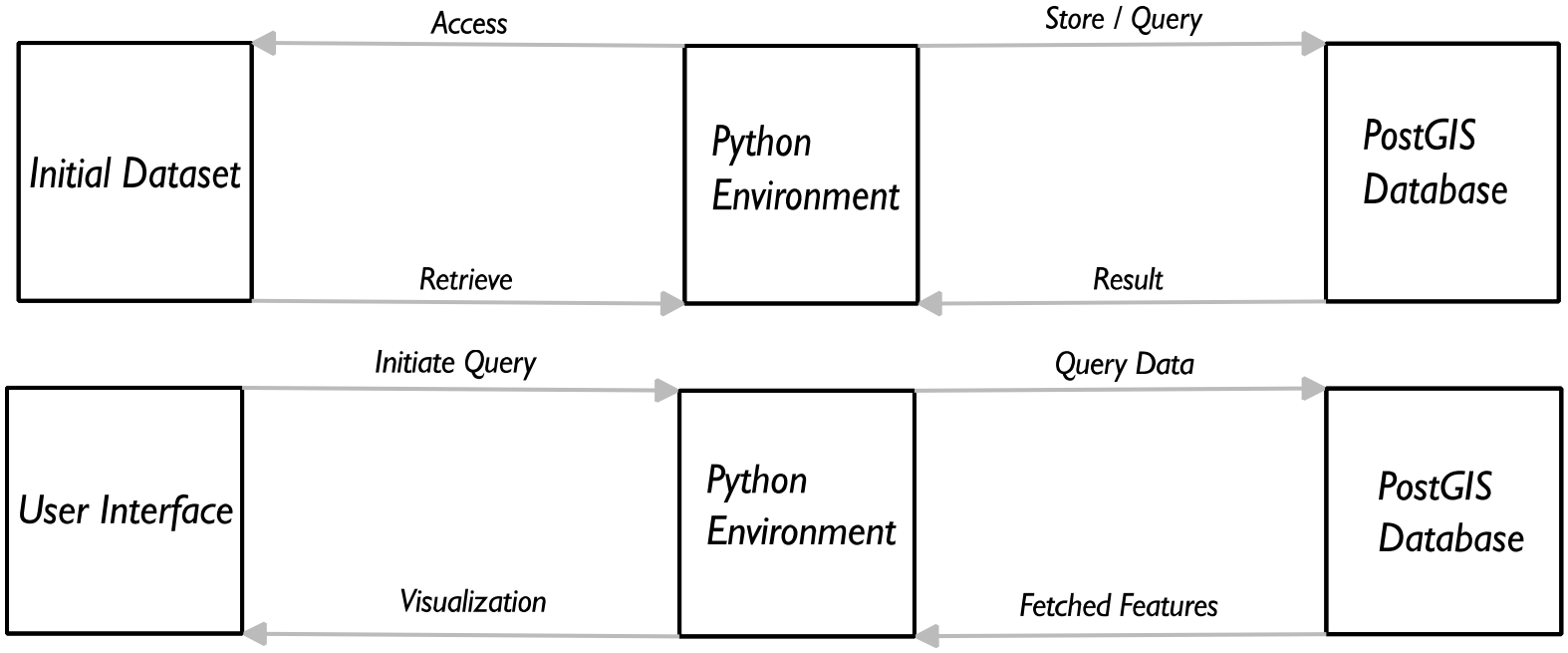


- There is room for research to build concrete relationship between importance values and number of features.
- Obviously the relation is based on selection of importance values and also the region of interest.

Road Network SSC, Implementation

How does it work in reality?

- The implemented solution is formed by two blocks:
  - Data importer
  - Data query



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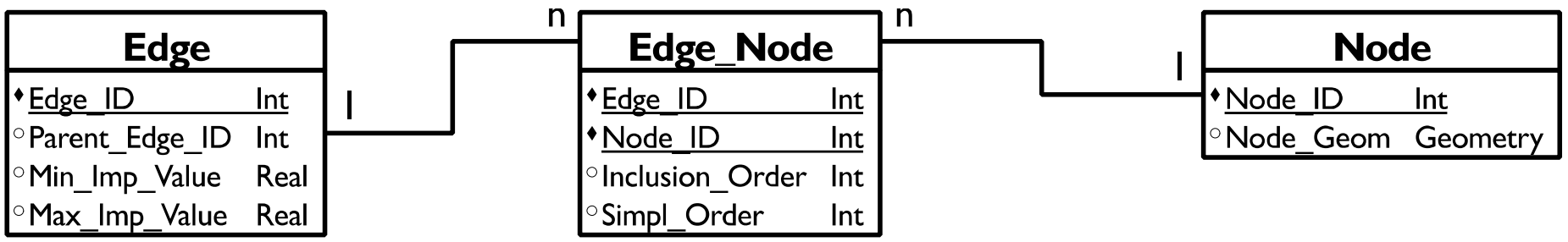
Road Network SSC, Impl.

Softwares used...

Software Name	**Usage**
Python	Programming Language
PostgreSQL	RDBMS
PostGIS	Additional spatial functionalities to PostgreSQL
GDAL	Geometry library
NetworkX	Graph analysis library

Road Network SSC, Impl.

How is the data stored?



- The database contains three main data entities:
  - Node: contains node data (including node geometry).
  - Edge: contains edge data and the hierarchy.
  - Edge-Node-Relation: keeps the relation between nodes and edges. It carries both inclusion relation and also simplification order.

Road Network SSC, Impl.

User interface...

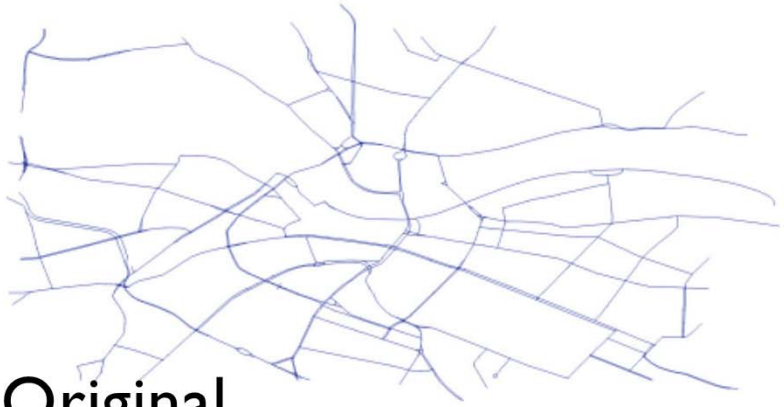
- The implemented preview uses web browser as the user interface.
- SVG has been selected as the visualization format.
  - Element path is used to show the segments:

<path d="M 13.7468588 51.0647456 L 13.7467282 51.0639843 13.7466772 51.0638025 13.746655 51.0637721" />

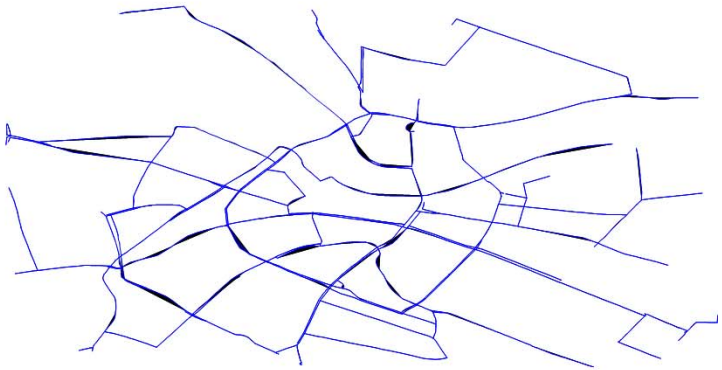
- Test data from OpenStreetMap data of Dresden (major roads layer).

Road Network SSC, Impl.

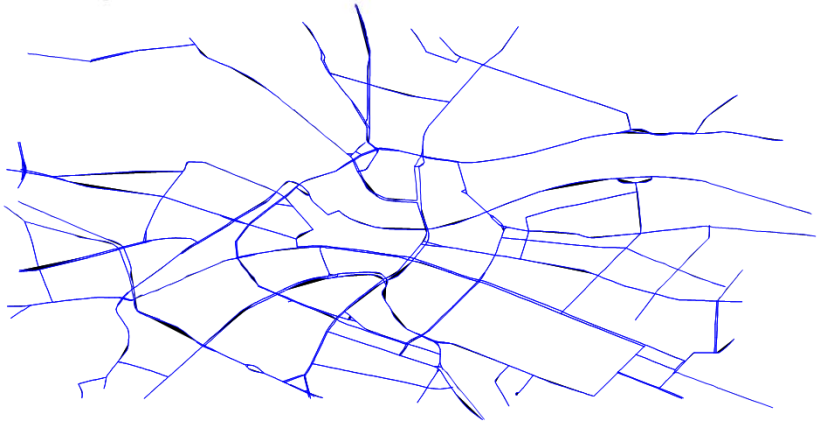
Results...



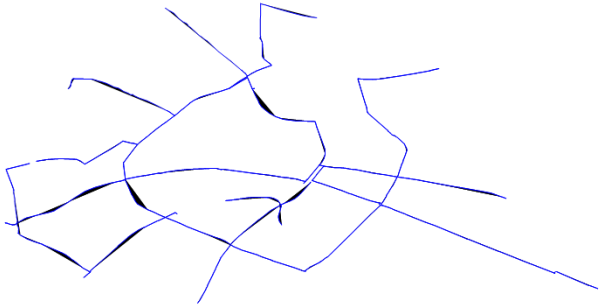
Original



Result Set 2



Result Set 1



Result Set 3

Road Network SSC, Impl.

Let's check it...

- Demo?

Conclusions and Outlook

Research outcomes and road to the future...

- The first effort of adaptation of road networks datasets on SSC has been theoretically analyzed and also practically implemented. This effort covers development of hierarchical data model and also inter-LoD smoothing.
- Combination of road networks with area and point data in an SSC maybe investigated in the future.
- Deterministic relation between importance values and the number of features can be research feed for potential researchers.
- There is room for researches regarding smoothing strategies for different generalization operators.

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Questions?

Thank YOU...

Thanks for your attention, are there any questions?