Automated schematization for thematic maps

Good afternoon!

Jakob Listabarth
Defense

M.Sc. Cartography, University of Twente
October 25th, 2021
Outline

1. Motivation
2. Objectives
3. Results
4. Conclusion
5. Outlook
Motivation
Motivation

relajaelcoco.com  @thegeographypin  studiomuti.co.za/
»A good schematic map requires a lot of work by a graphic artist.«

Objectives
Main research objective

Create a prototype of an interactive, web-based map schematization tool.
2– Objectives

Main research objective

Create a prototype of an interactive, web-based map schematization tool.

Sub-objectives

A Define cartographic requirements for schematized thematic maps.

B Define software requirements for a web-based schematization tool.

C Compare algorithms and approaches for schematization.

D Implement a suitable algorithm into a web-based prototype.
Results
Research question A

What are best practices for designing the geographic layer of thematic maps and how are they compatible with the properties of schematized maps?

Method literature review
Defining schematization

“... a process that uses cartographic generalisation operators in such a way as to produce maps of a lower graphical complexity compared to maps of the same scale;”

Defining schematization

schematization and generalization are driven and bound by diverging intentions

Properties of schematized maps

— low visual complexity
— simple geometric shapes
— preservation of geographic relations
— geometric shapes match the reader’s mental picture

Thematic maps and legibility

— implement a visual hierarchy based on an intellectual hierarchy of map elements
— contrast as mean to establish such a hierarchy
— geographic layer sets the stage for the thematic overlay
— formalized by Bertin (1967) as 3 rules of legibility

Legibility regarding the base layer

— greater angles, enclosed by longer edges
— less detail, less focus
Base and thematic layer

A

B

C

D

E

F
Research question A

What are best practices for designing the geographic layer of thematic maps and how are they compatible with the properties of schematized maps?

High contrasts in angles, density, and level of detail increase map legibility.

Schematization promotes them.

Yet, schematization on its own cannot guarantee such contrasts.
Research question

Which **types of automated schematization** exist and what are their cartographic (**visual**) and technical (**software**) characteristics?

**Method** literature review
Methodology

— systematic comparison based on literature review
  — geometric properties
  — computational complexity
Schematization types

— by input geometry

Schematization types

—by style, the visual appearance
—depends on geometric properties

Geometric schematization properties

— vertex restriction
— flexibility vs. complexity
Geometric schematization properties

— topologically safe by preserving face-to-face adjacencies
— required for cartographic purposes

Geometric schematization properties

— area preserving: $b_A^A : c_A^A = b_B^B : c_B^B$, but $b_A^A : c_A^A \nless b_C^C : c_C^C$

— relevant in the context of area preserving projections

Examined approaches

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Style</th>
<th>A</th>
<th>T</th>
<th>V</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meulemans et al.</td>
<td>2021</td>
<td>C-Oriented</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, O(n² + m \cdot n)</td>
</tr>
<tr>
<td>Buchin et al.</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, O(n³)</td>
</tr>
<tr>
<td>Meulemans</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>np-complete</td>
</tr>
<tr>
<td>Meulemans</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>np-complete</td>
</tr>
<tr>
<td>van Goethem et al.</td>
<td>2015</td>
<td>Arcs</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, O(n³)</td>
</tr>
<tr>
<td>van Dijk et al.</td>
<td>2014</td>
<td>Arcs</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, O(n³ h log n)</td>
</tr>
<tr>
<td>van Goethem et al.</td>
<td>2013</td>
<td>Arcs, Bezier Curves</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>p, O(n³ k)</td>
</tr>
<tr>
<td>Cicerone and Cermignani</td>
<td>2012</td>
<td>C-Oriented</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>p, O(m n² log)</td>
</tr>
<tr>
<td>Reimer and Meulemanns</td>
<td>2011</td>
<td>Parallelism</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>np-hard</td>
</tr>
<tr>
<td>Meulemans et al.</td>
<td>2010</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, O(n³)</td>
</tr>
<tr>
<td>Heimlich and Held</td>
<td>2008</td>
<td>Circular Biarcs</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, O(n log n)</td>
</tr>
</tbody>
</table>
## Examined approaches

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Style</th>
<th>A</th>
<th>T</th>
<th>V</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meulemans et al.</td>
<td>2021</td>
<td>C-Oriented</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, $O(n^2 + m n)$</td>
</tr>
<tr>
<td>Buchin et al.</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, $O(n^2)$</td>
</tr>
<tr>
<td>Meulemans</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>np-complete</td>
</tr>
<tr>
<td>Meulemans</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>np-complete</td>
</tr>
<tr>
<td>van Goethem et al.</td>
<td>2015</td>
<td>Arcs</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, $O(n^2)$</td>
</tr>
<tr>
<td>van Dijk et al.</td>
<td>2014</td>
<td>Arcs</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, $O(n^2 h \log n)$</td>
</tr>
<tr>
<td>van Goethem et al.</td>
<td>2013</td>
<td>Arcs, Bezier Curves</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>p, $O(n^3 k)$</td>
</tr>
<tr>
<td>Cicerone and Cermignani</td>
<td>2012</td>
<td>C-Oriented</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>p, $O(m n^2 \log)$</td>
</tr>
<tr>
<td>Reimer and Meulemanns</td>
<td>2011</td>
<td>Parallelism</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>np-hard</td>
</tr>
<tr>
<td>Meulemans et al.</td>
<td>2010</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, $O(n^3)$</td>
</tr>
<tr>
<td>Heimlich and Held</td>
<td>2008</td>
<td>Circular Biarcs</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, $O(n \log n)$</td>
</tr>
</tbody>
</table>
## Examined approaches

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Style</th>
<th>A</th>
<th>T</th>
<th>V</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meulemans et al.</td>
<td>2021</td>
<td>C-Oriented</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, O(n² + m n)</td>
</tr>
<tr>
<td>Buchin et al.</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, O(n²)</td>
</tr>
<tr>
<td>Meulemans</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>np-complete</td>
</tr>
<tr>
<td>Meulemans</td>
<td>2016</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>np-complete</td>
</tr>
<tr>
<td>van Goethem et al.</td>
<td>2015</td>
<td>Arcs</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, O(n²)</td>
</tr>
<tr>
<td>van Dijk et al.</td>
<td>2014</td>
<td>Arcs</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, O(n³ h log n)</td>
</tr>
<tr>
<td>van Goethem et al.</td>
<td>2013</td>
<td>Arcs,Bezier Curves</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>p, O(n³ k)</td>
</tr>
<tr>
<td>Cicerone and Cermignani</td>
<td>2012</td>
<td>C-Oriented</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>p, O(m n² log)</td>
</tr>
<tr>
<td>Reimer and Meulemanns</td>
<td>2011</td>
<td>Parallelism</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>np-hard</td>
</tr>
<tr>
<td>Meulemans et al.</td>
<td>2010</td>
<td>C-Oriented</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>p, O(n³)</td>
</tr>
<tr>
<td>Heimlich and Held</td>
<td>2008</td>
<td>Circular Biarcs</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>p, O(n log n)</td>
</tr>
</tbody>
</table>
Research question

Which **types of automated schematization** exist and what are their cartographic (*visual*) and technical (*software*) characteristics?

Schematization algorithms generate various styles and exhibit various geometric properties.

Few preserve area and topology.

The C-oriented approach by Buchin et al. (2016) has low computational complexity but is flexible regarding output.
Research question B

What are the system features, requirements, quality attributes, and possible other requirements?

Method requirement engineering
Methodology

— requirement engineering processes
  — elicitation → documentation, validation → verification

— different levels of requirement information
  — from general to specific
  — business → user → functional

User types

— starting point for user scenario
— basis for features and functional requirements

<table>
<thead>
<tr>
<th>Cartographer</th>
<th>Information designer</th>
</tr>
</thead>
<tbody>
<tr>
<td>— GIS workflow</td>
<td>— Graphic tools</td>
</tr>
<tr>
<td>— spatial focus</td>
<td>— visual focus</td>
</tr>
</tbody>
</table>
Features
### Functional requirements

<table>
<thead>
<tr>
<th>02-a</th>
<th>03-a</th>
<th>04-a</th>
<th>05-a</th>
<th>06-a</th>
<th>07-a</th>
</tr>
</thead>
<tbody>
<tr>
<td>08-a</td>
<td>09-a</td>
<td>10-a</td>
<td>11-a</td>
<td>17-a</td>
<td>22-a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>01-b</th>
<th>02-b</th>
<th>11-b</th>
<th>12-b</th>
<th>13-b</th>
<th>14-b</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-b</td>
<td>16-b</td>
<td>18-b</td>
<td>19-b</td>
<td>20-b</td>
<td>21-b</td>
</tr>
<tr>
<td>23-b</td>
<td>24-b</td>
<td>25-b</td>
<td>28-b</td>
<td>29-rc</td>
<td>26-rc</td>
</tr>
<tr>
<td>27-rc</td>
<td>30-rc</td>
<td>31-rc</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Functional requirements

If the input data is not a region (geometry type “polygon” or “multipolygon”) the program shall exit and inform the user on valid input data types.
Research question B

What are the **system** features, (**data** requirements), **external interface** requirements, **quality attributes**, and possible other **requirements**?

The system shall validate the input data’s geometry and handle projections.

The user interface shall offer meaningful feedback and allow an efficient schematization setup.
Research question

To which extent does the prototype satisfy the specified requirements?

Method prototyping, requirement verification
Methodology

Prototyping
— mock-up prototype → horizontal
— proof-of-concept prototype → vertical

Verification
— automated and manual verification methods
— combination of automated unit tests and manual tests
— test protocol
3– Results

invalid input

Error

The input data you chose is not a region. Only feature of geometry type Polygon or MultiPolygon are allowed. Please check whether your input contains Point or Line features.
3– Results
Design iterations
Demo Time!
Verification results

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>02-a</td>
<td>03-a</td>
<td>04-a</td>
<td>05-a</td>
<td>06-a</td>
<td>07-a</td>
<td></td>
</tr>
<tr>
<td>08-a</td>
<td>09-a</td>
<td>10-a</td>
<td>11-a</td>
<td>17-a</td>
<td>22-a</td>
<td></td>
</tr>
<tr>
<td>01-b</td>
<td>02-b</td>
<td>11-b</td>
<td>12-b</td>
<td>13-b</td>
<td>14-b</td>
<td></td>
</tr>
<tr>
<td>15-b</td>
<td>16-b</td>
<td>18-b</td>
<td>19-b</td>
<td>20-b</td>
<td>21-b</td>
<td></td>
</tr>
<tr>
<td>23-b</td>
<td>24-b</td>
<td>25-b</td>
<td>28-b</td>
<td>29-rc</td>
<td>26-rc</td>
<td></td>
</tr>
<tr>
<td>27-rc</td>
<td>30-rc</td>
<td>31-rc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fail | Pass
Research question ③

To which extent does the prototype satisfy the specified requirements?

Met 6 out of 12 requirements for alpha release. Important system capabilities need to be implemented for further verification. Focus on graphical user interface and user feedback.
Conclusion
Create a prototype of an interactive, web-based map schematization tool.

— such a tool is feasible
— computational time constraints decreased performance
— the tool’s robustness needs further attention
Iterative process

— prototyping implies iterations
— thesis groundwork for such a process

4—Conclusion
5. Outlook
A good schematic map requires a lot of work by a graphic artist. «
Future research

— A schematize point features and in 3D space
— B compare algorithmic implementations instead of literature-based comparison
— C meaningful level of detail for input
— C interfaces for integration into cartographic workflows
— D examine the use of preview subsets
— D suggest default values depending on input

— C conduct suggested user study to validate requirements
— D refine requirements
— D implement simplification algorithm
References

› **Avelar, S.** (2002). Schematic maps on demand: Design, modeling and visualization (p. 130) [ETH Zurich; Application/pdf].


› **Meulemans, W.** (2014). Similarity measures and algorithms for cartographic schematization [Technische Universiteit Eindhoven].


Questions?

Thank you for your time.

Happy to hear your thoughts, ideas and suggestions. 😊✨
Appendix
Links

Github
— www.figma.com/proto/TM2xmAQqVaF9K8P8EKFq7Q/Schemapify?scaling=contain

Mock-up prototype (figma)
— schemapify-demo.netlify.app/

Proof-of-concept prototpye
— github.com/jakoblistabarth/area-preserving-polygon-schematization
Doubly connected edge list (DCEL)
## Results requirement verification

<table>
<thead>
<tr>
<th>ID</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-a</td>
<td>The system shall be able to parse geoJSON as input data.</td>
</tr>
<tr>
<td>3-a</td>
<td>If the input data is not a region (geometry type “polygon” or “multipolygon”) the program shall exit and inform the user on valid input data types.</td>
</tr>
<tr>
<td>4-a</td>
<td>If the input data is not a valid geoJSON the program shall exit and the user shall be informed.</td>
</tr>
<tr>
<td>5-a</td>
<td>If the input data is too detailed, i.e., if it exceeds a maximum number of edges or vertices, the program shall exit and the user shall be informed.</td>
</tr>
<tr>
<td>6-a</td>
<td>The system shall preserve potential attributes attached to the inputs features in the output.</td>
</tr>
<tr>
<td>7-a</td>
<td>The system shall preserve the number of features of the input in the output.</td>
</tr>
<tr>
<td>8-a</td>
<td>The system shall be able to generate a DCEL from a geoJSON.</td>
</tr>
<tr>
<td>9-a</td>
<td>The system shall be able to generate a geoJSON from a DCEL.</td>
</tr>
<tr>
<td>10-a</td>
<td>While the data is being processed, the user shall be informed that the application is processing.</td>
</tr>
<tr>
<td>11-a</td>
<td>The user shall be able to specify a regular set of directions (without beta-shift) of the schematization.</td>
</tr>
<tr>
<td>17-a</td>
<td>The system shall display the schematized region in the map view after the schematization is finished.</td>
</tr>
<tr>
<td>22-a</td>
<td>The user shall be able to track the progress of the schematization.</td>
</tr>
</tbody>
</table>
Legibility and graphic density

— “an optimum number of marks per cm²”
— graphic density as a factor of legibility
Legibility of angles

— angles close to 0° or 180° are less legible
— angles enclosed by long edges are legible
Legibility and retinal separation

— overall amount of ink
— ratio of ink for “the predictable” and “the unpredictable”