Labeling vario-scale maps

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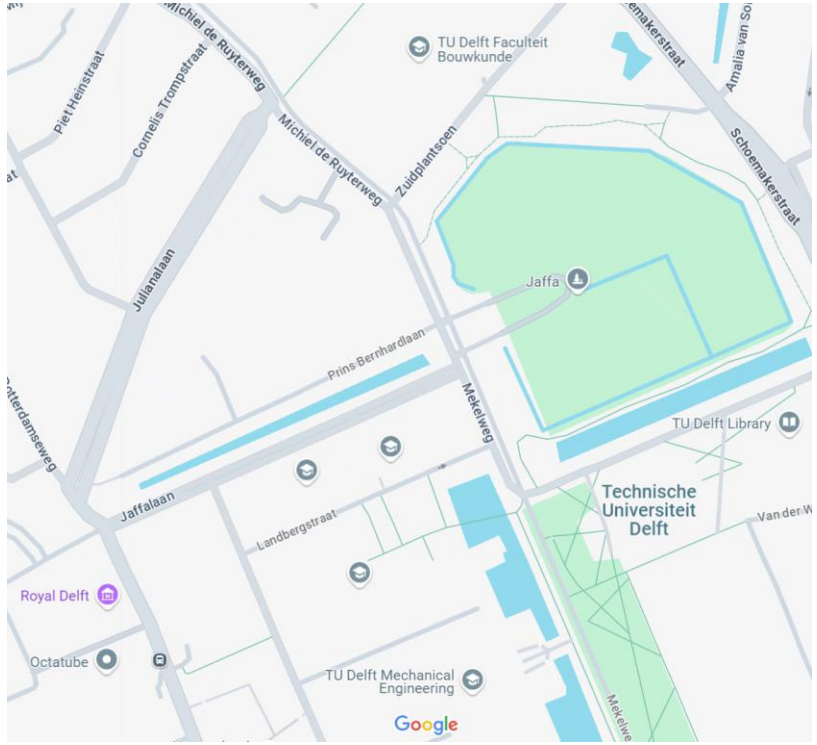
Introduction

Map labels are important identifiers for geographic features, and their effective placement is important for the readability and usability of maps.

Many label placement algorithms are designed for static or fixed-scale maps, where the map is viewed at discrete predetermined scales.

Maps without labels

Maps with labels

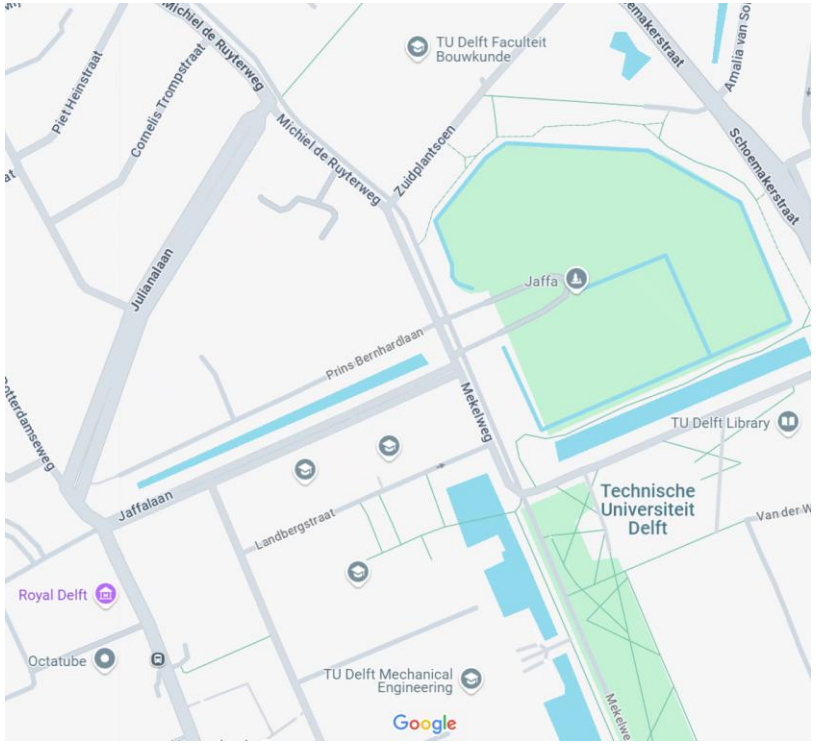


Google Maps

Introduction

In a vario-scale scenario, every slight change in scale potentially affects which features are shown, how their geometries are represented, and consequently, which labels are displayed and where.

There is a need for strategies that enable labels to adjust their placement continuously and smoothly, ensuring that as the map scale changes, label positions and visibility update in a gradual manner.



Google Maps

Vario-scale Maps

Research Questions

Main Question

How can labels be dynamically placed and adjusted on vario-scale maps to maintain readability, usability, and visual coherence across continuously changing scales?

Sub Q1	Sub Q2	Sub Q3	Sub Q4	Sub Q5
Label placement requirements	Optimal placement techniques	Dynamic adjustments	Data structure and retrieval	Dynamic display

Research Questions

Main Question

How can labels be dynamically placed and adjusted on vario-scale maps to maintain readability, usability, and visual coherence across continuously changing scales?

Sub Q1	Sub Q2	Sub Q3	Sub Q4	Sub Q5
Label placement requirements	Optimal placement techniques	Dynamic adjustments	Data structure and retrieval	Dynamic display

What are the hard and soft requirements for optimal vario-scale label placement?

Research Questions

Main Question

How can labels be dynamically placed and adjusted on vario-scale maps to maintain readability, usability, and visual coherence across continuously changing scales?

Sub Q1	Sub Q2	Sub Q3	Sub Q4	Sub Q5
Label placement requirements	**Optimal placement techniques**	Dynamic adjustments	Data structure and retrieval	Dynamic display

How can the optimal positions for labels be determined for both elongated and more compact features, ensuring spatial alignment and visual clarity?

Research Questions

Main Question

How can labels be dynamically placed and adjusted on vario-scale maps to maintain readability, usability, and visual coherence across continuously changing scales?

Sub Q1	Sub Q2	Sub Q3	Sub Q4	Sub Q5
Label placement requirements	Optimal placement techniques	**Dynamic adjustments**	Data structure and retrieval	Dynamic display

How can labels be smoothly transitioned across scales, minimizing positional shifts during scale changes, while maintaining readability and visual continuity?

Research Questions

Main Question

How can labels be dynamically placed and adjusted on vario-scale maps to maintain readability, usability, and visual coherence across continuously changing scales?

Sub Q1	Sub Q2	Sub Q3	Sub Q4	Sub Q5
Label placement requirements	Optimal placement techniques	Dynamic adjustments	**Data structure and retrieval**	Dynamic display

How can label-related data be structured and stored efficiently to support dynamic rendering in vario-scale maps?

Research Questions

Main Question

How can labels be dynamically placed and adjusted on vario-scale maps to maintain readability, usability, and visual coherence across continuously changing scales?

Sub Q1	Sub Q2	Sub Q3	Sub Q4	Sub Q5
Label placement requirements	Optimal placement techniques	Dynamic adjustments	Data structure and retrieval	**Dynamic display**

How can label text be effectively placed on maps in a way that integrates with the underlying geographic features and supports continuous scale changes?

Research Scope

A simplifying assumption: the label set at any scale of the map is a set of labels for features that are present at that level of detail.

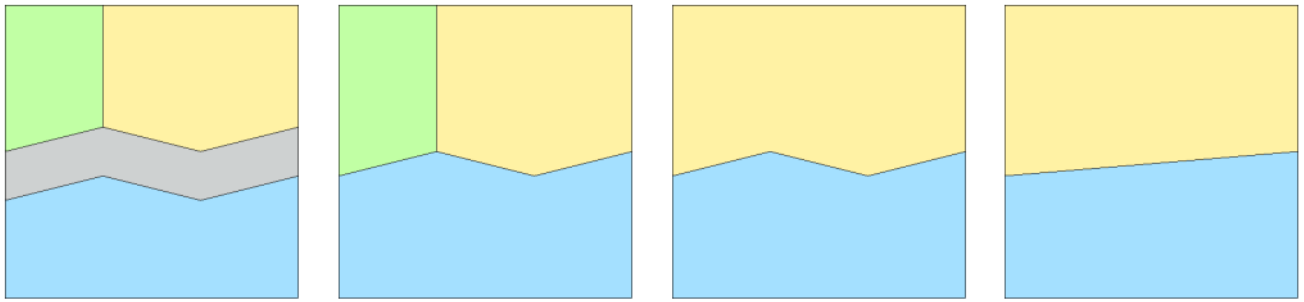
The research:

- excludes map rotation as a factor
- will not address labeling for multi-language or non-Latin scripts
- is confined to 2D vario-scale maps and does not extend to 3D mapping
- does not focus on creating new label content
- does not aim to develop new methods for text rendering
- does not consider curved labels that follow the shape of features

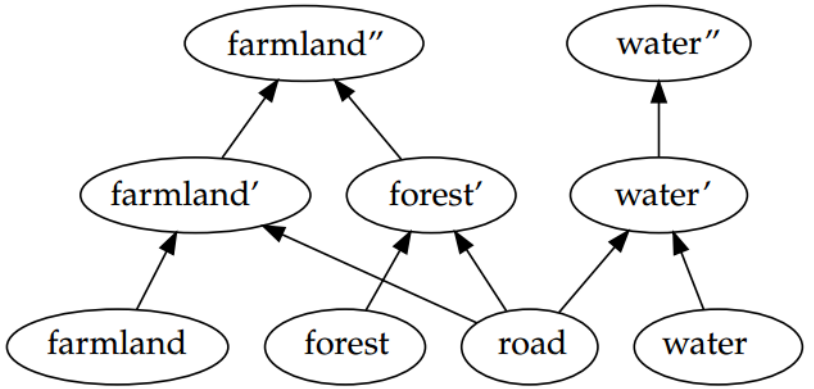
How do we build a vario-scale map?

Related Work - topological Generalized Area Partition (tGAP)

Begins with a highly detailed planar partition of the map (at the largest scale available) and then progressively simplifies this partition by merging or eliminating less significant features



(a) Original map (b) Result of collapse (c) Result of merge (d) Result of simplify

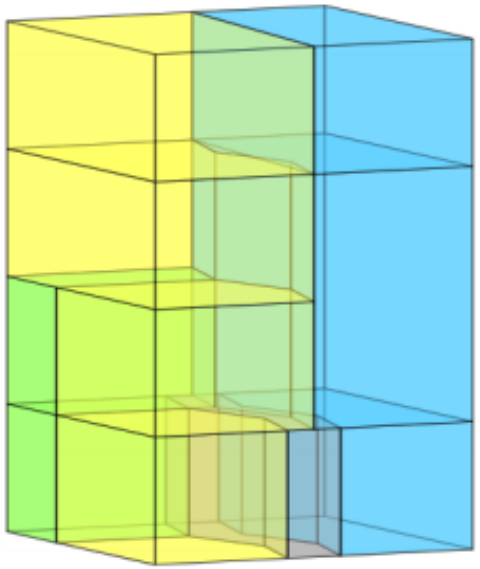


(e) Corresponding tGAP structure

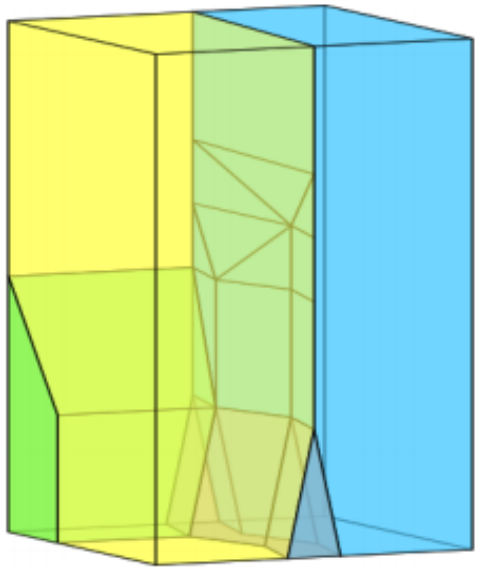
Map fragments and corresponding tGAP structure (van Oosterom and Meijers[2012b])

Related Work - Space-scale Cube(SSC)

2D features from a map are extruded into a third dimension, where the height represents scale.
Each 2D map can be derived by slicing the SSC horizontally at a specific scale, yielding a planar partition.



(a) SSC for the classic tGAP structure



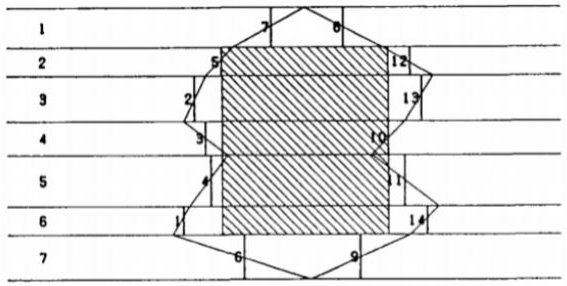
(b) SSC for the smooth tGAP structure

Space-scale cube(SSC) representation in 3D (van Oosterom and Meijers [2012b])

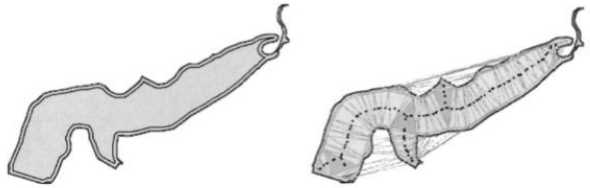
What are existing labeling methods?

Related Work - Static Label Placement

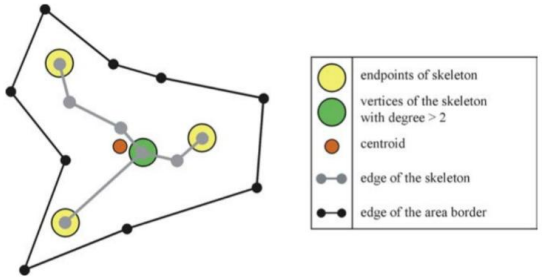
Area



Maximal candidate boxes (Van Roessel)

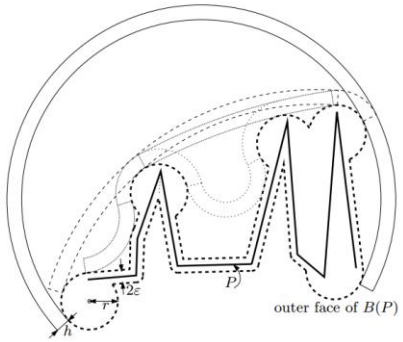


Erosion and skeleton (Barrault)



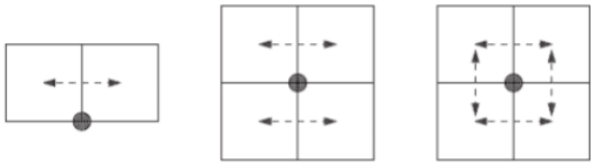
Erosion and skeleton(Dörschlag)

Line



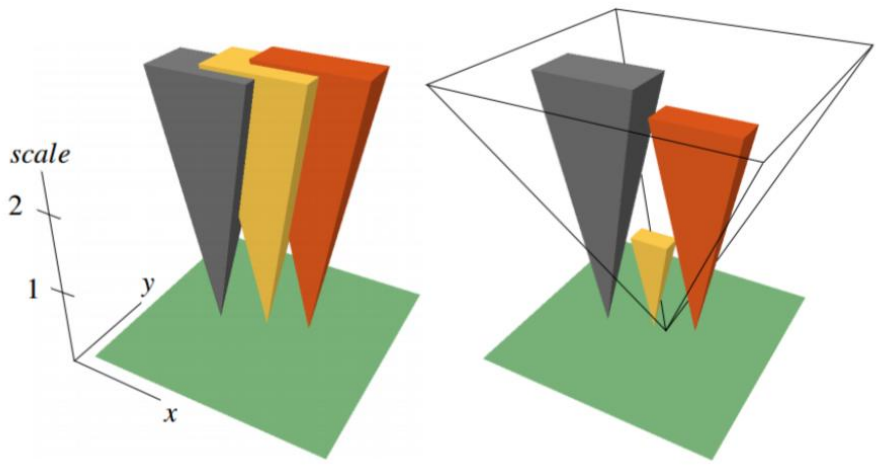
Refine candidate strip(Wolff et al.)

Point

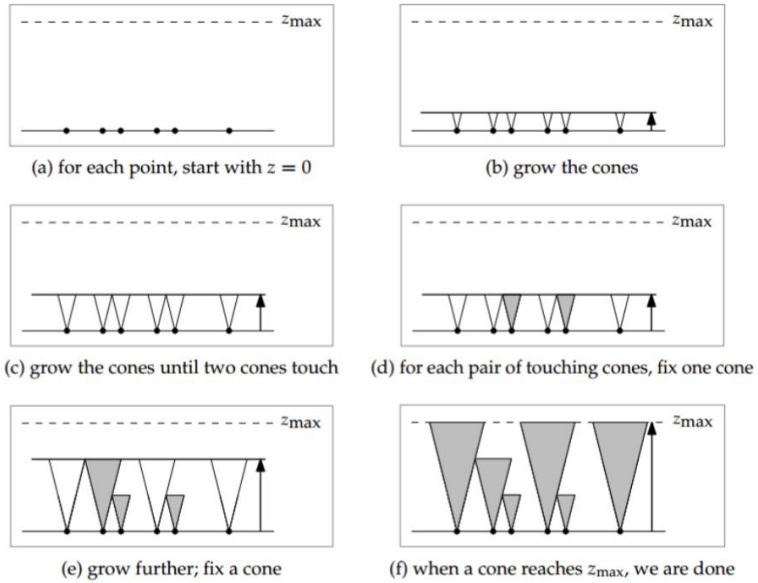


Top-, two- and four-slider model(Van Kreveld)

Related Work - Dynamic Label Placement



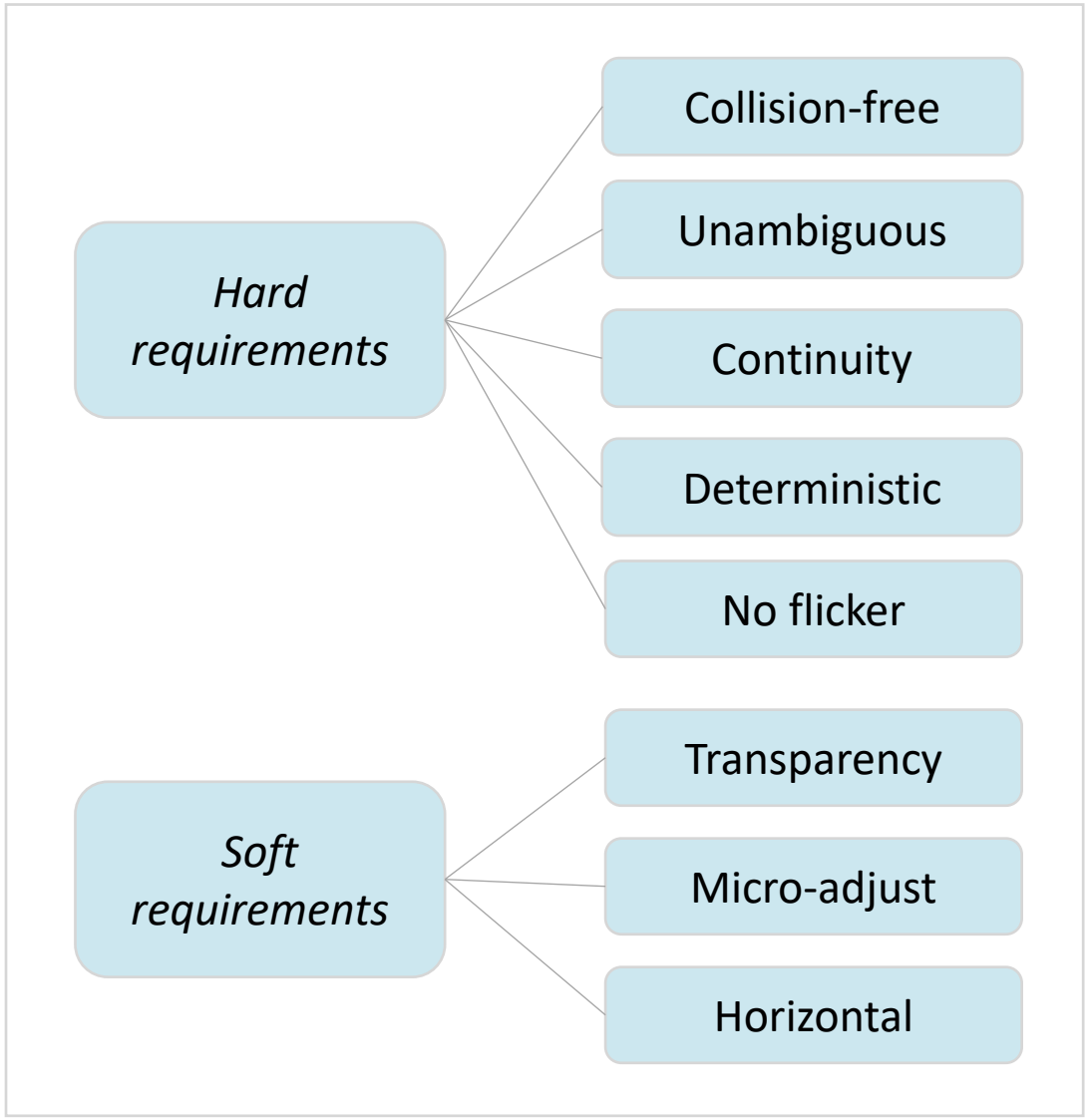
Been et al. proposed:
- Labels maintain a constant screen size across scales.
- Invariant point placement.
- The label's visibility at different scales forms a continuous 3D cone.
- Active Range Optimization (ARO): select the optimal scale intervals during which labels remain visible, while maximizing label presence across scales and avoiding conflicts.



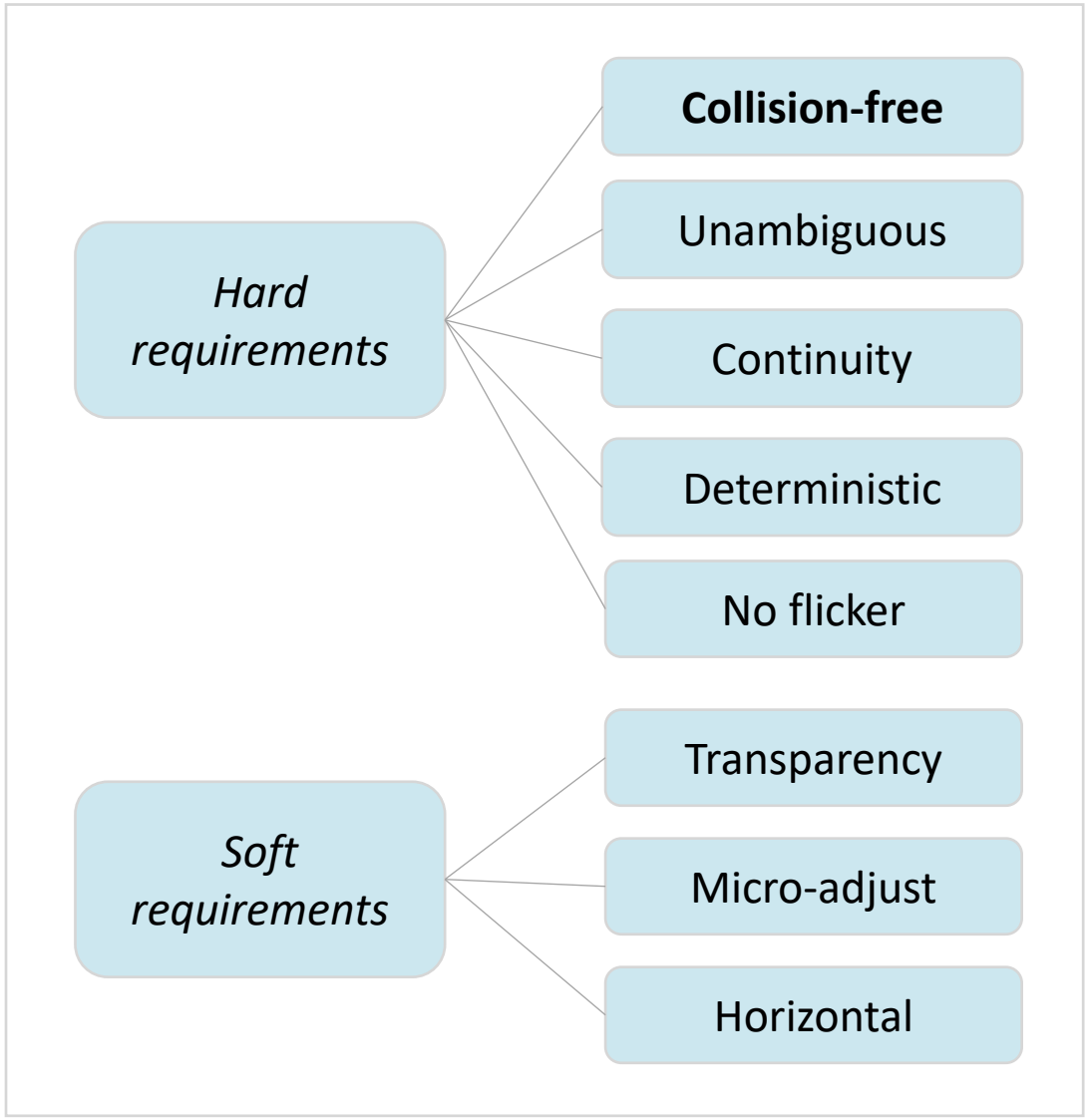
Schwartges's research:
- Growing-cones method begins with minimal active ranges and gradually expands them until conflicts arise.
- Shrinking-cones method starts with full visibility for labels and iteratively reduces their active ranges to resolve conflicts.

Requirements that guide the research

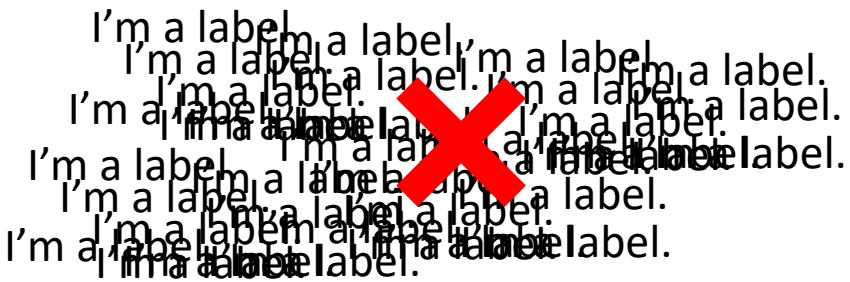
Label Placement Requirements



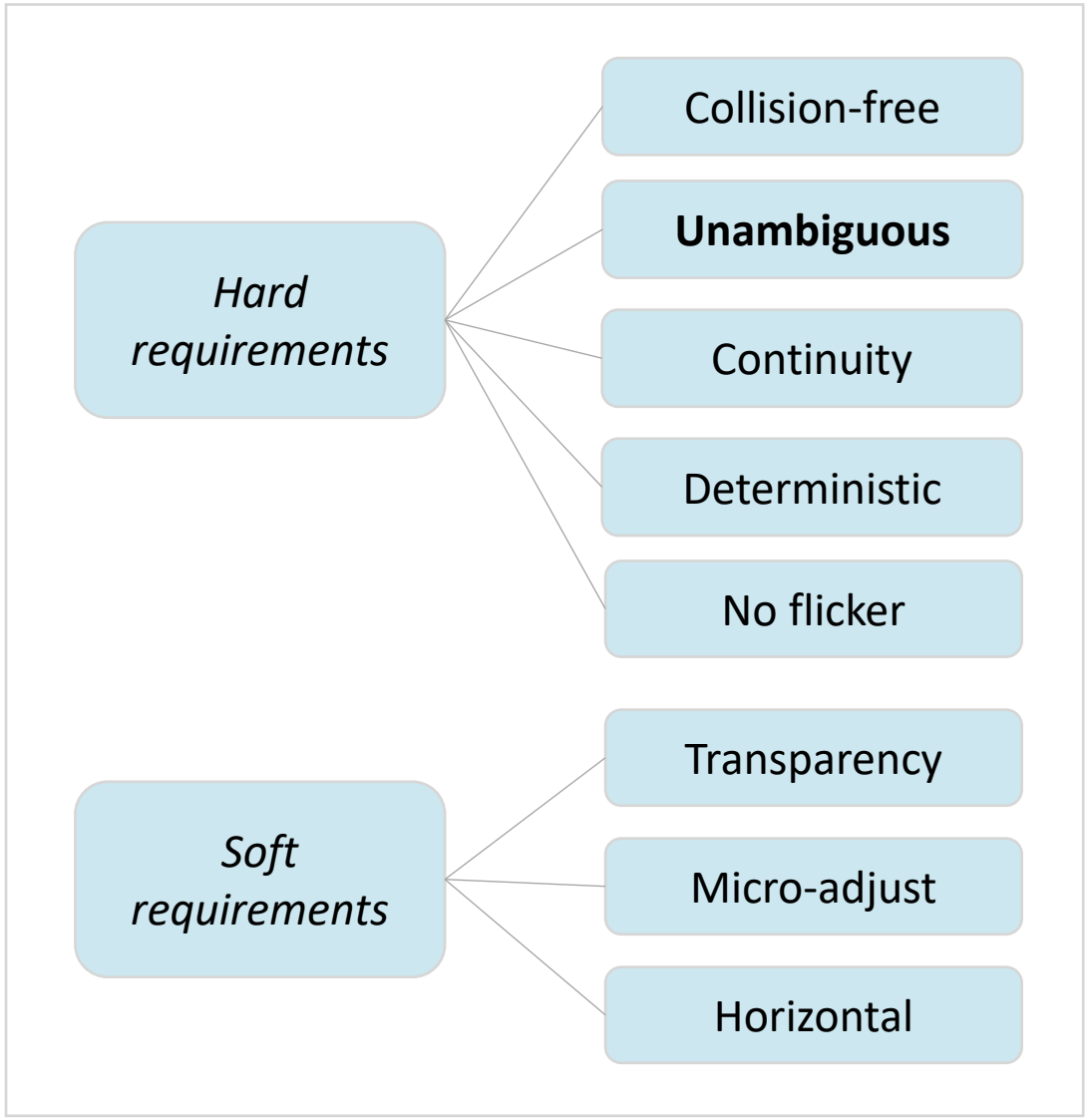
Label Placement Requirements



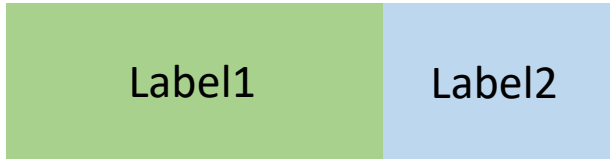
Collision-free rendering: at any visible scale, no two label bounding boxes may overlap in screen space as overlaps obscure text and reduce readability.



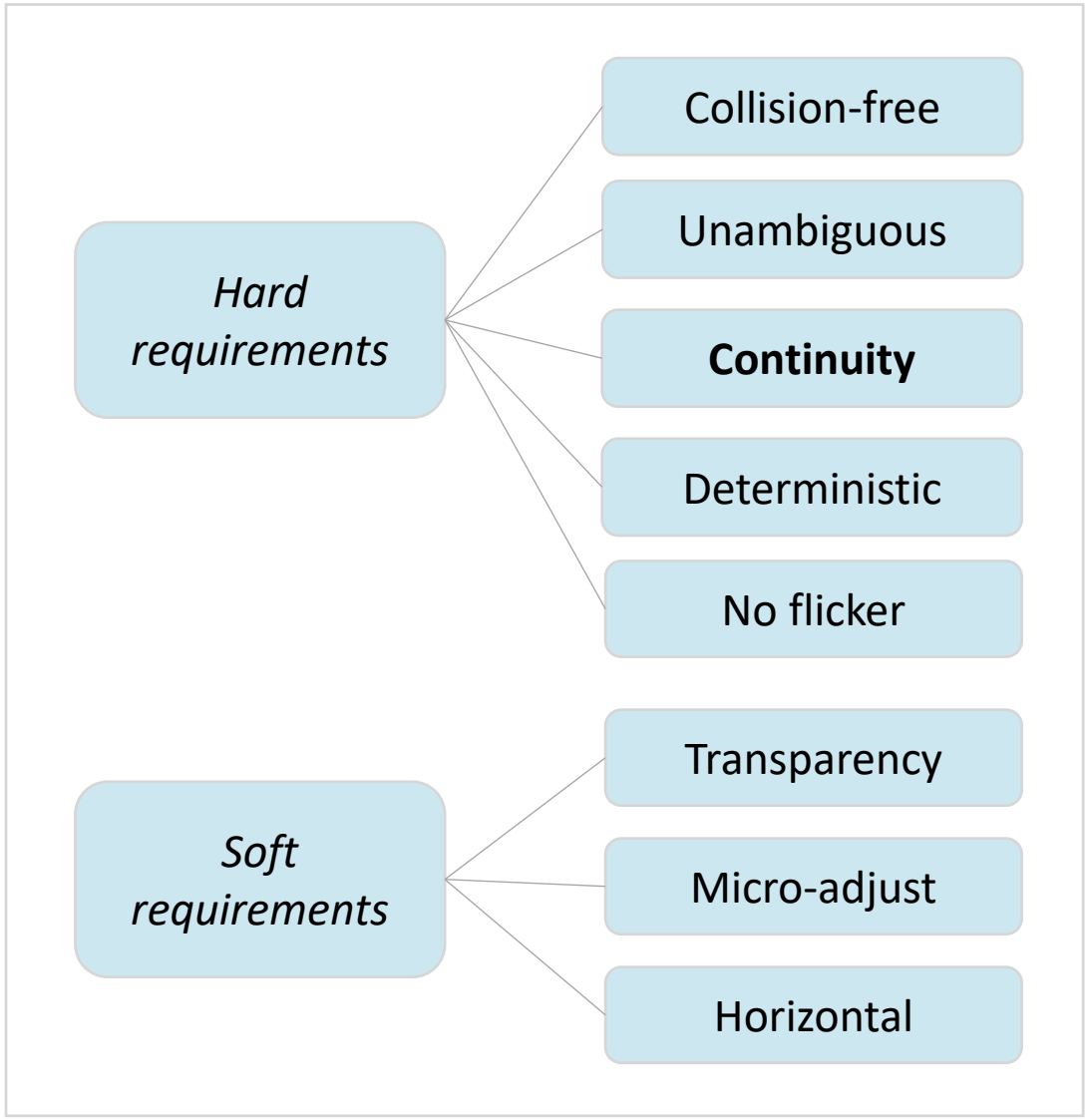
Label Placement Requirements



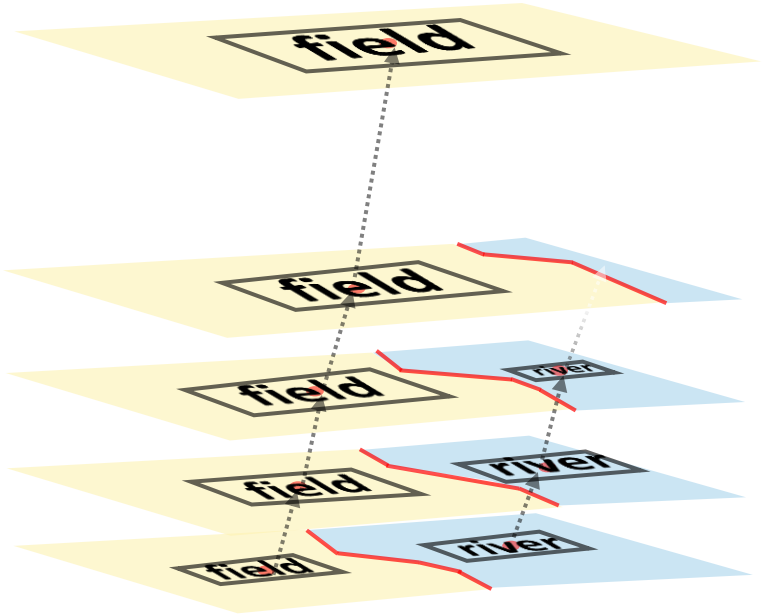
Unambiguous feature association: a label must be visually and semantically linked to exactly one map feature at any moment



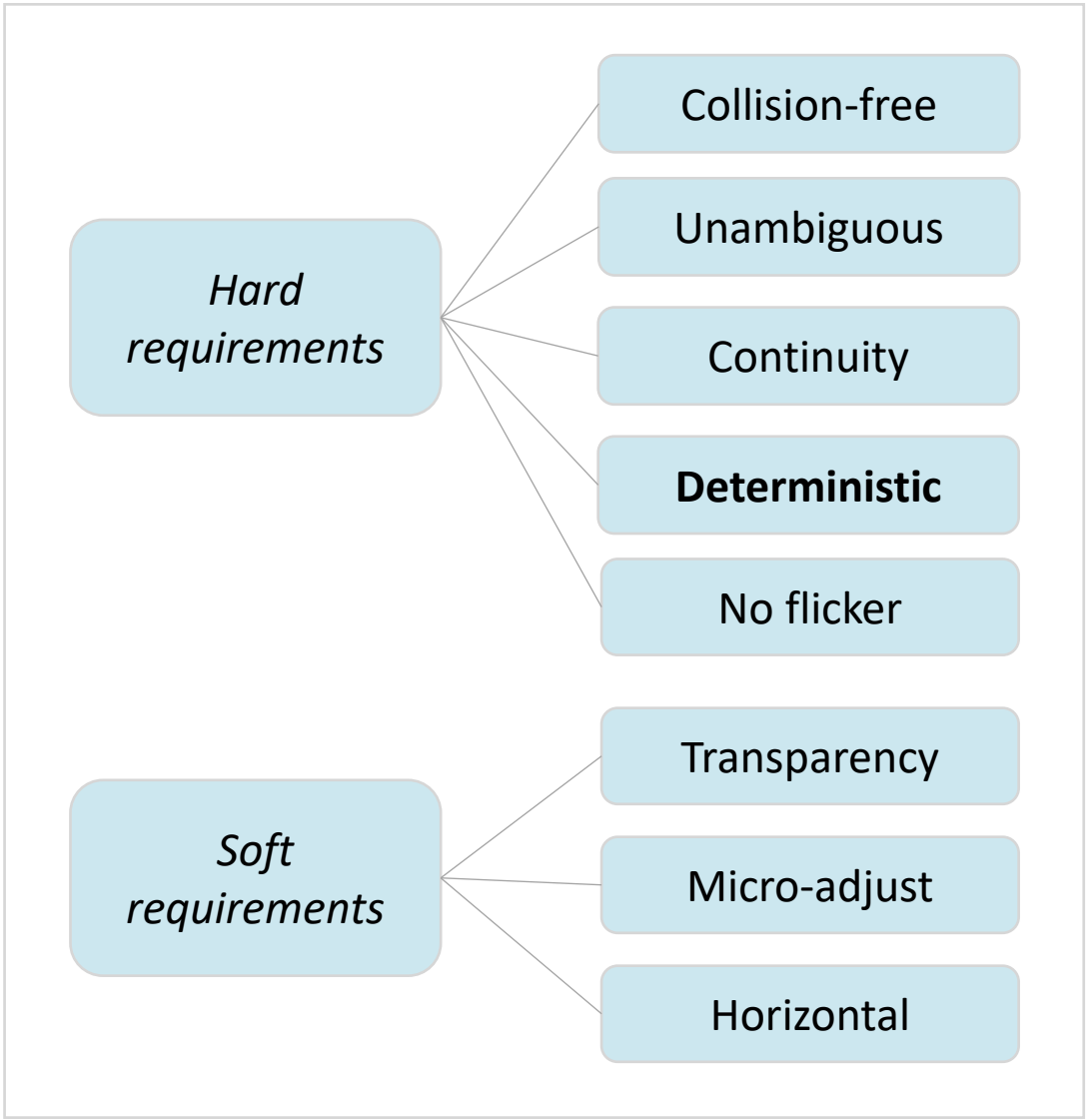
Label Placement Requirements



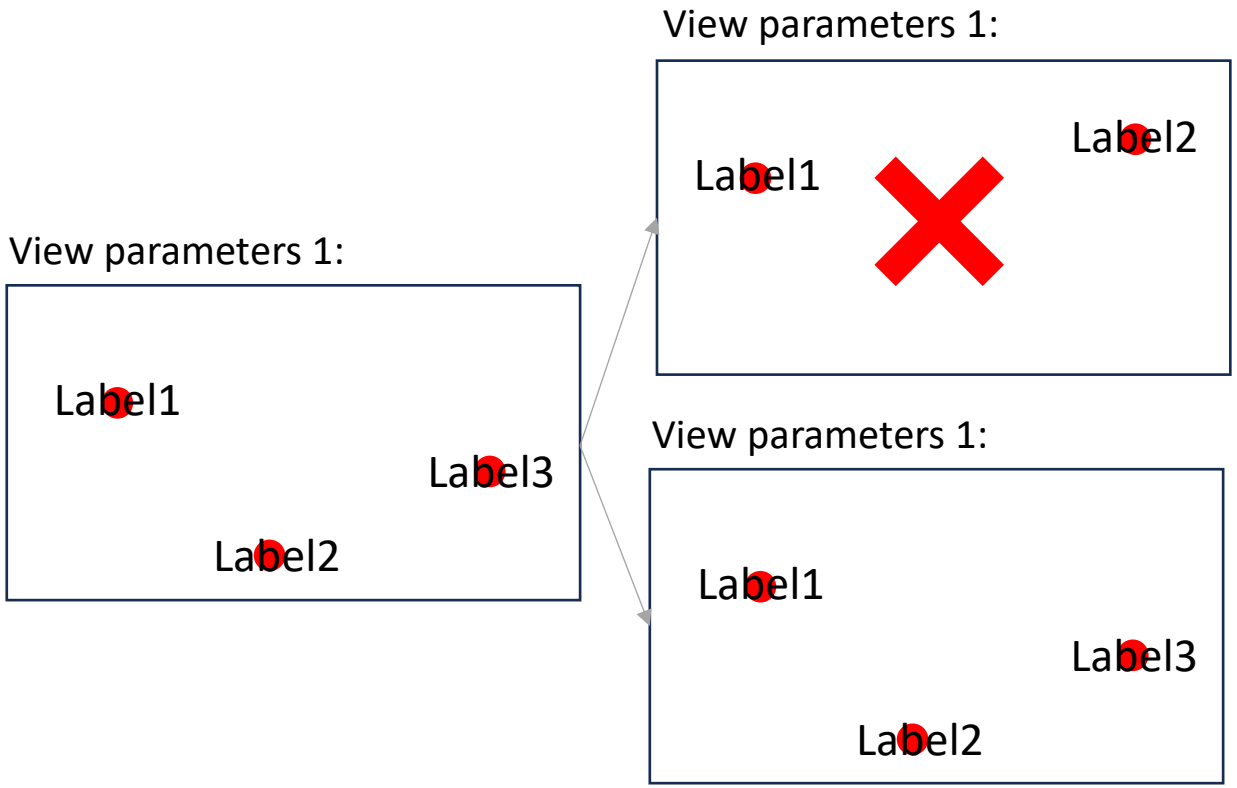
Label continuity during continuous zoom: label anchors must move smoothly as the view scale changes; abrupt repositioning should be forbidden.



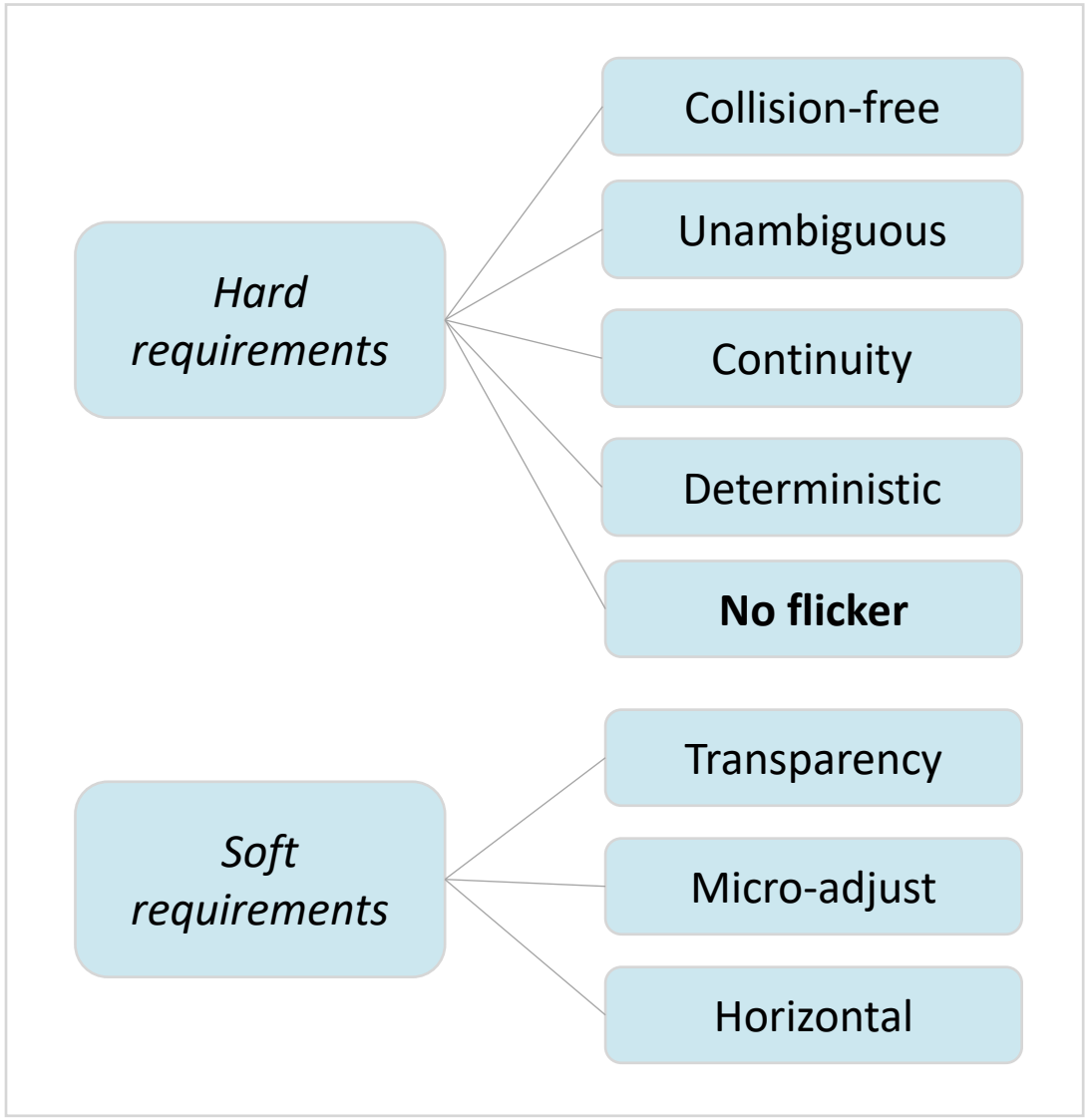
Label Placement Requirements



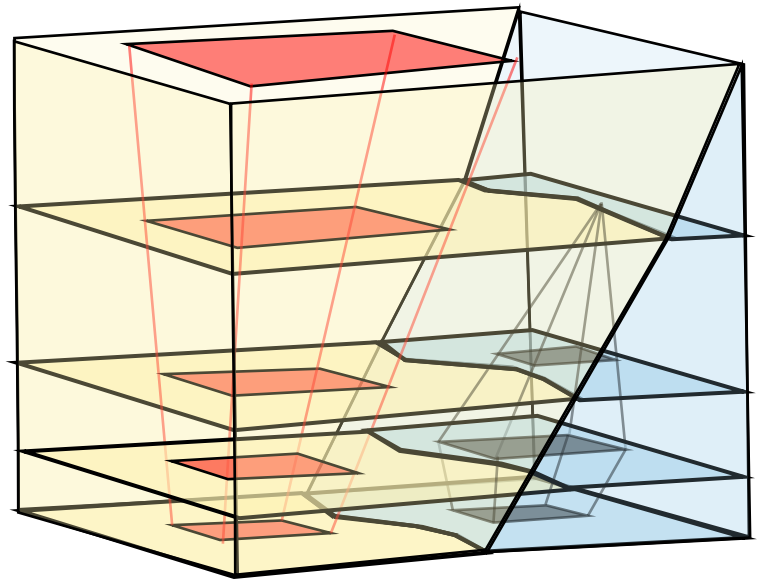
Deterministic priority model: given the same view parameters, the label selection and placement must be consistent and repeatable.



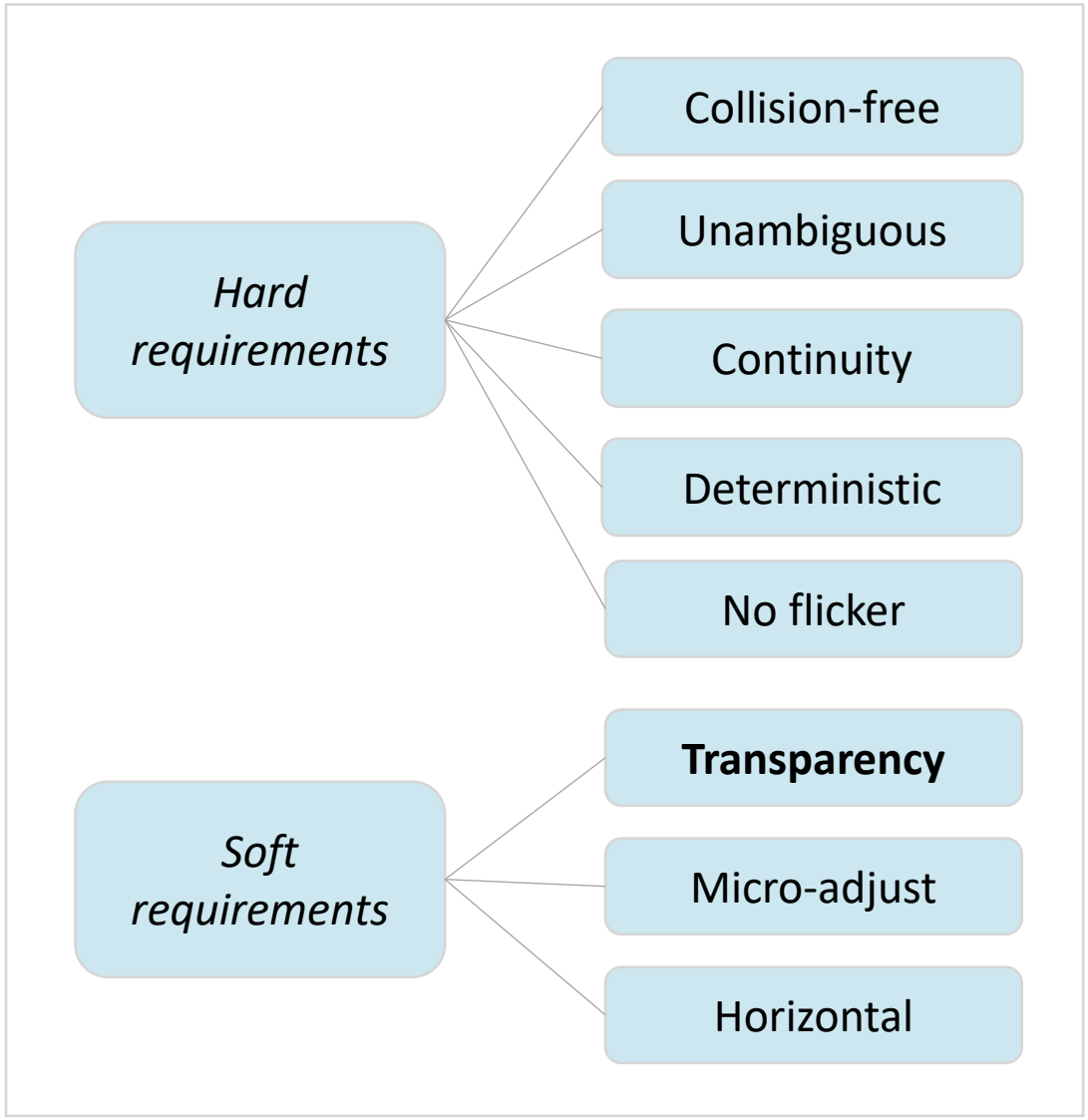
Label Placement Requirements



No flicker: labels should appear and disappear smoothly, without sudden flickers during interaction.



Label Placement Requirements

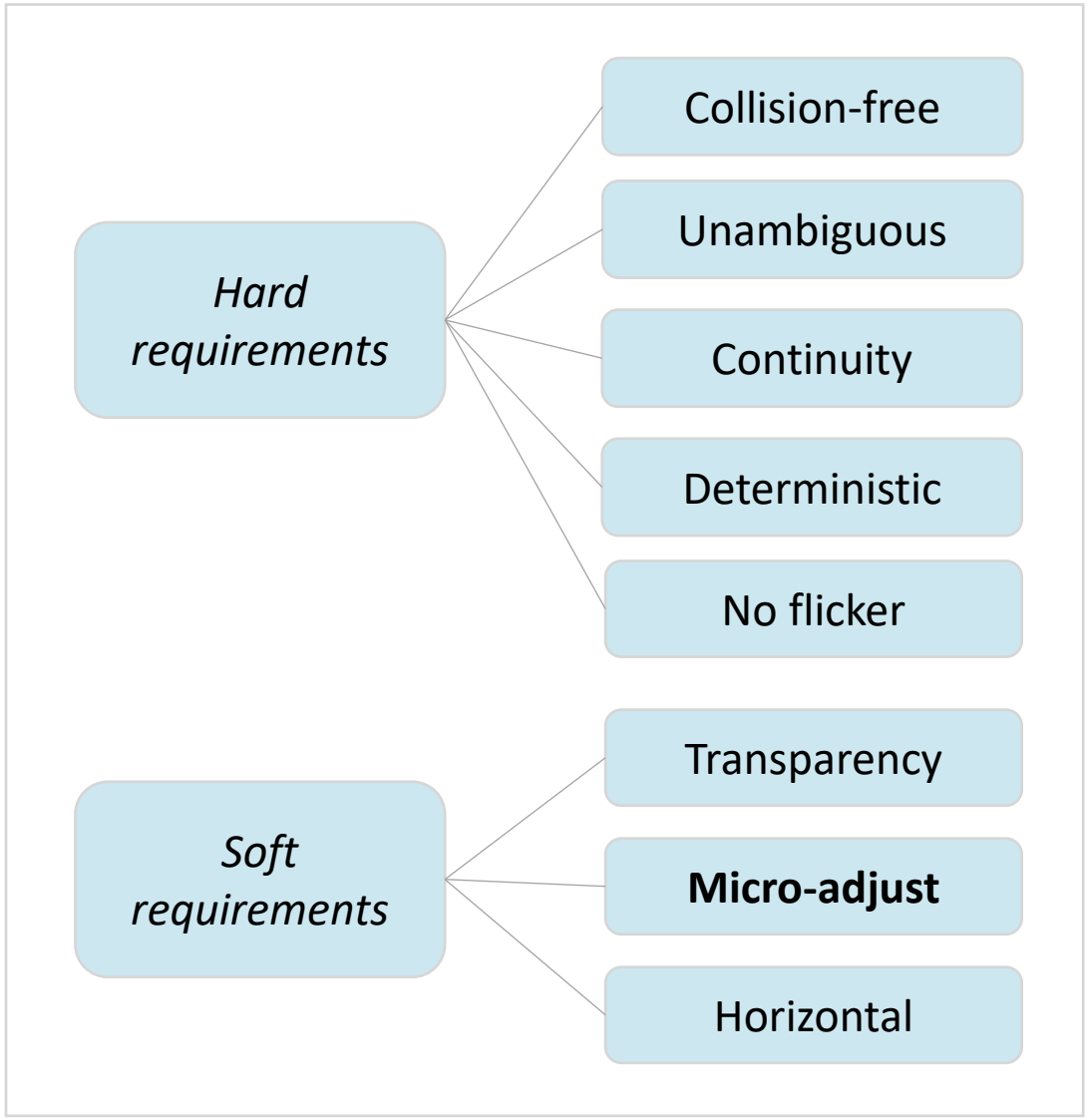


Avoid half-transparent rest state: labels should not remain partially transparent at rest, as this can cause confusion or misinterpretation.

I'm a fully visible label.

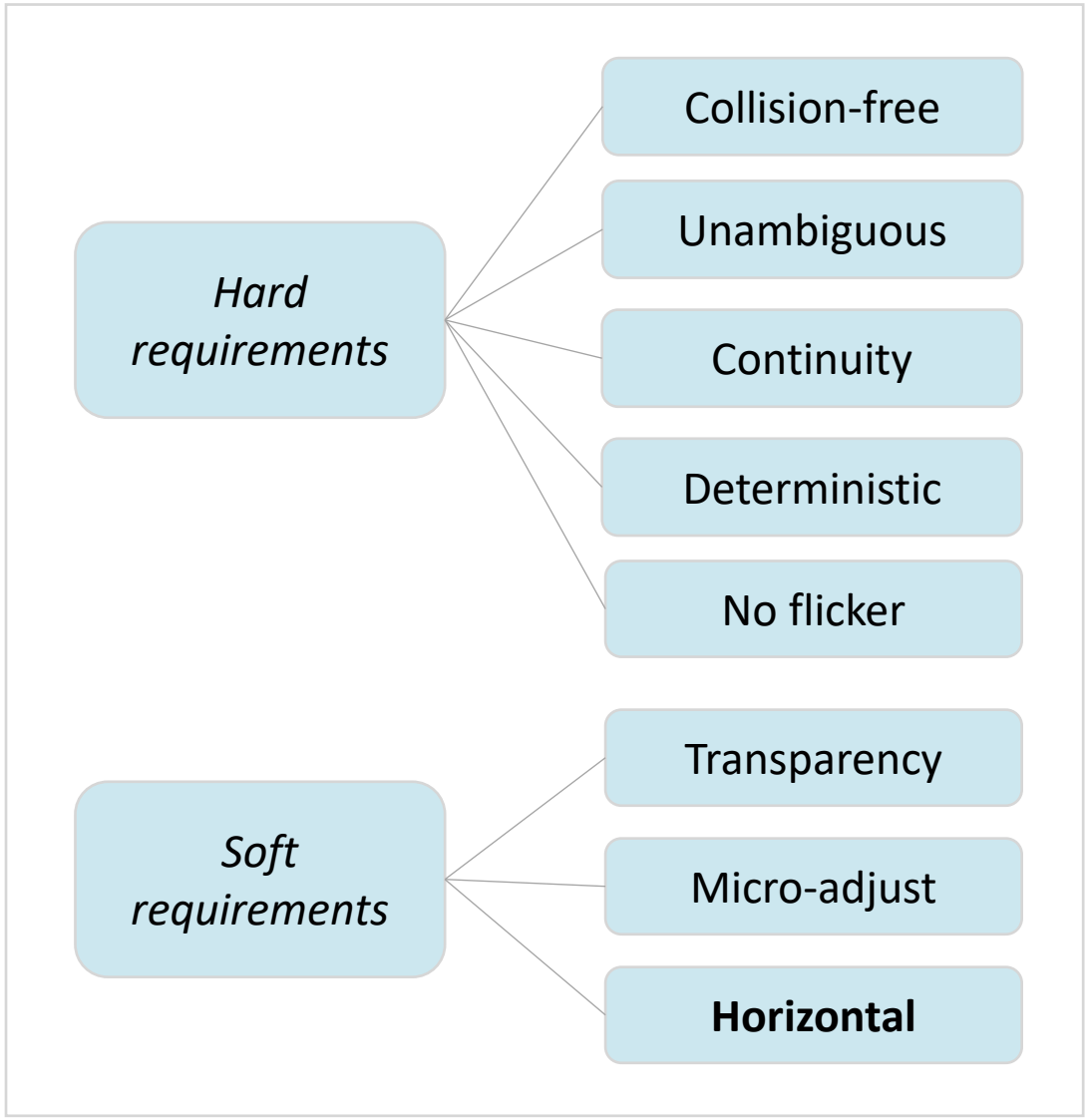
I'm a half-transparent label.

Label Placement Requirements



Micro-adjust before drop: if two labels overlap by less than a certain percentage of their areas, attempt a slight nudge before removing the lower-priority label. This may increase label density without compromising clarity.

Label Placement Requirements



Preserve horizontal orientation: when feasible, keep labels aligned horizontally to enhance legibility.

Where to put labels on the map?

Label Placement - Label Anchors for Elongated Geometries

Medial-axis-based skeleton

↓

Select important junction nodes

↓

Select primary paths between these nodes

↓

Midpoints of the long segments

↓

Label orientation angles

Label Placement - Label Anchors for Compact Geometries

Primary approach: the polygon's centroid

↓

Fallback approach: the pole of inaccessibility

↓

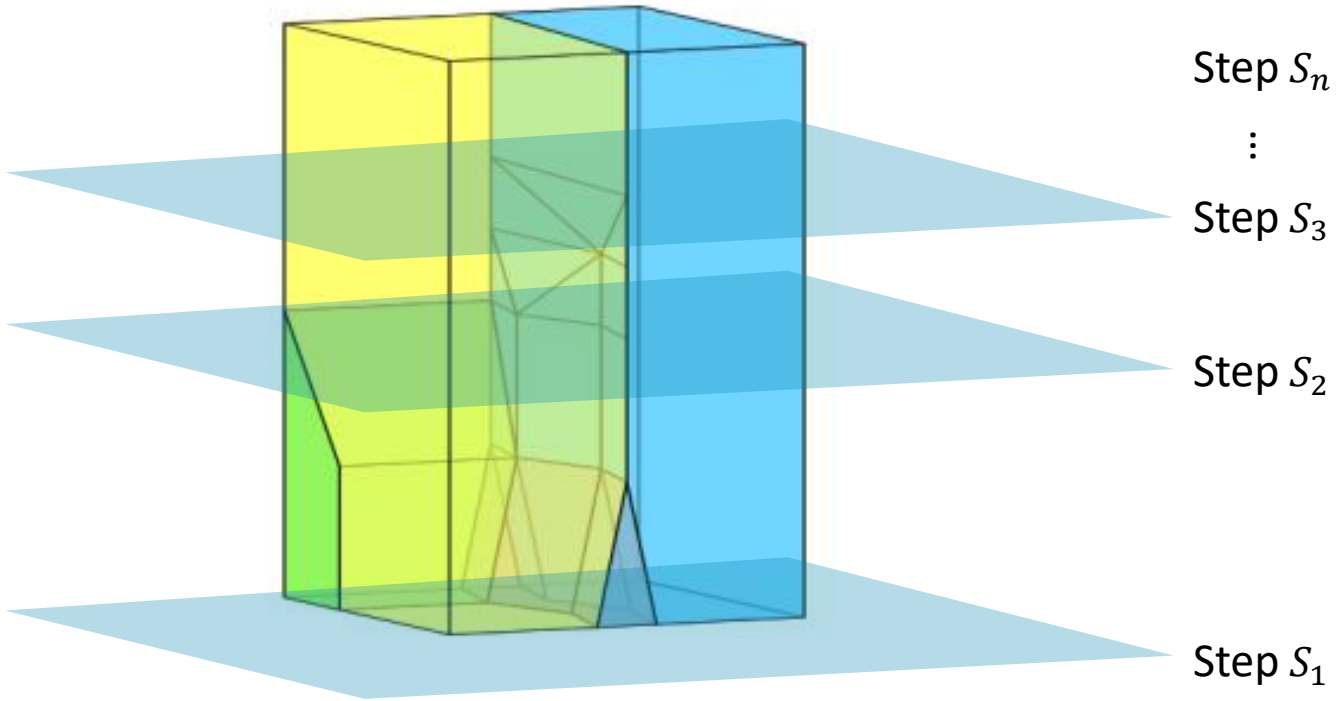
Label orientation angles

the polygon's minimum rotated rectangle containing the polygon: find the longer pair of sides and use their direction to define the label orientation

How to combine labels with vario-scale maps?

Polygonization from tGAP - Slice-based Method

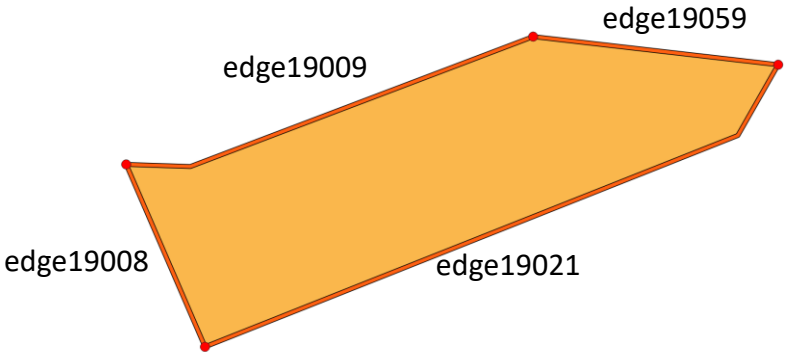
Base scale -> step value



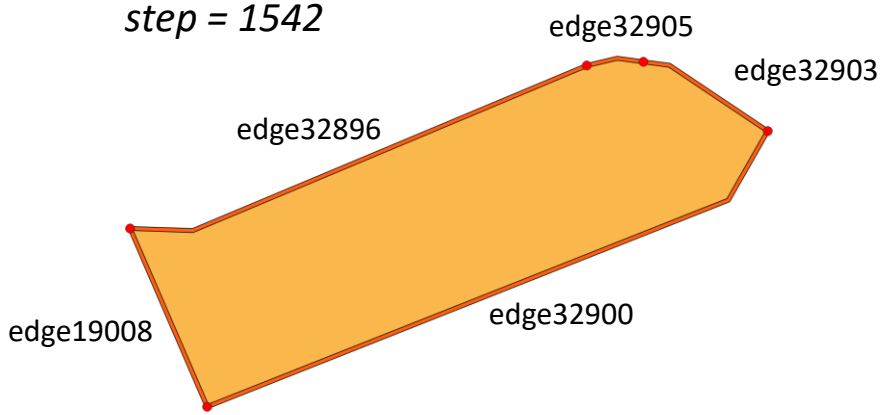
Polygonization from tGAP - Event-based Method

face_id = 9884 *step_low = 0* *step_high = 4229*

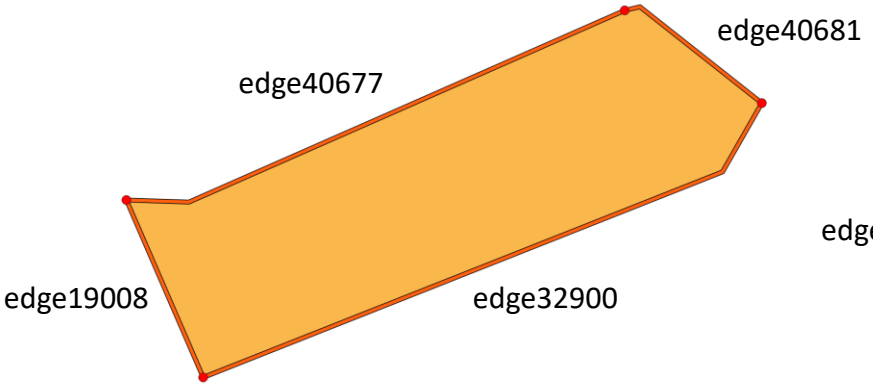
step = 0



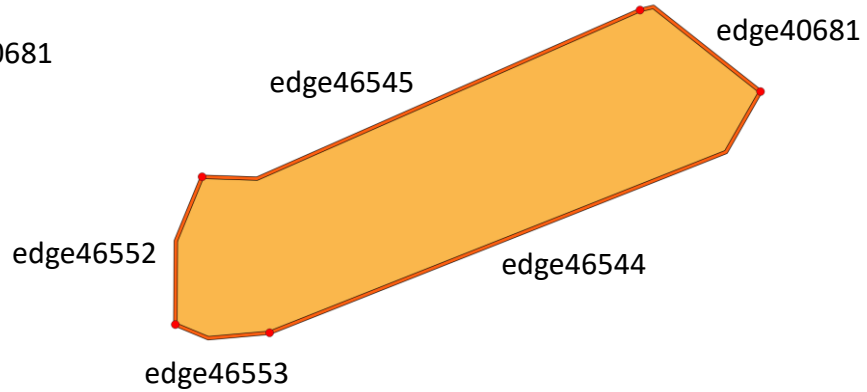
step = 1542



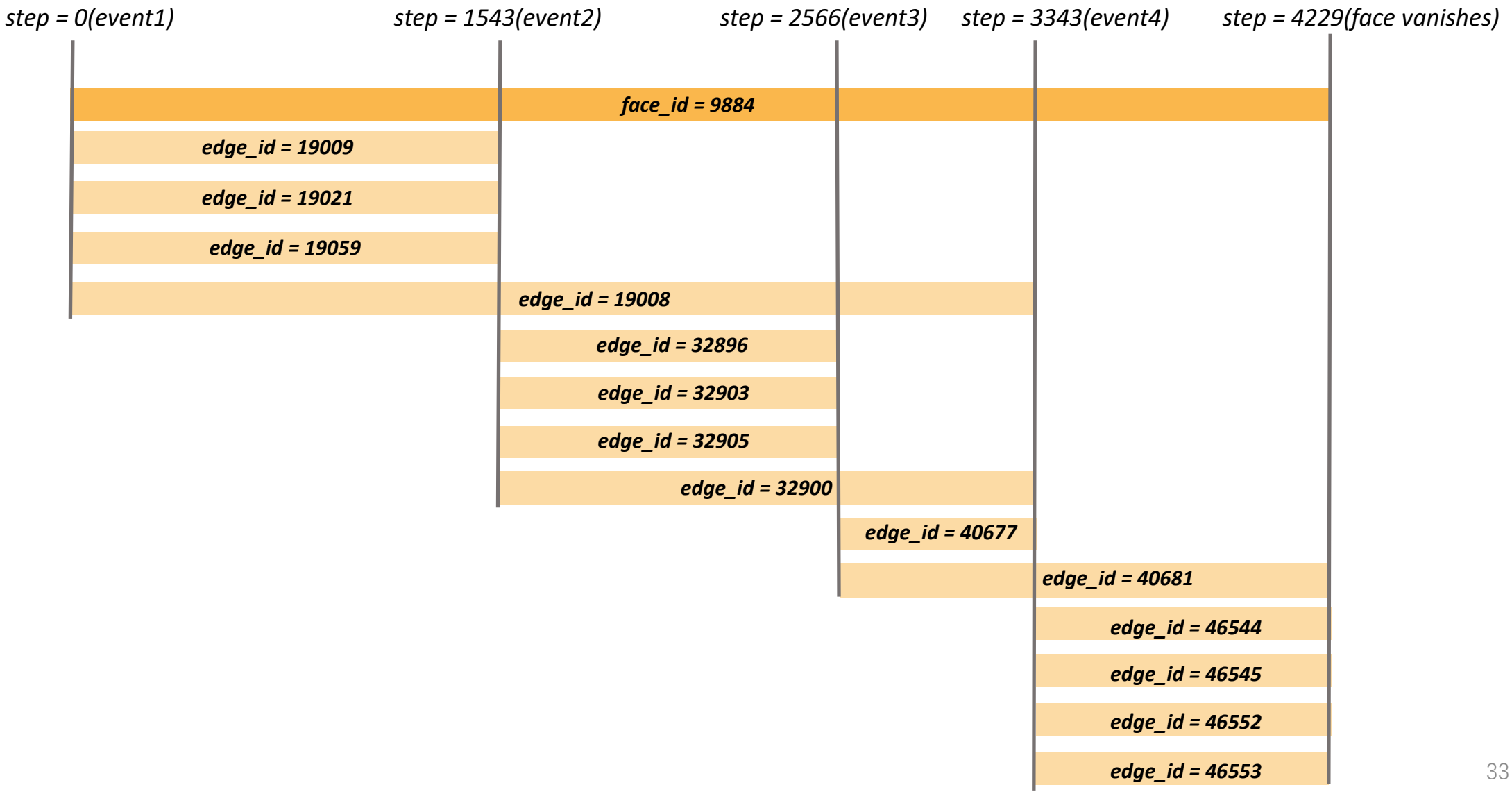
step=2566



step=3343

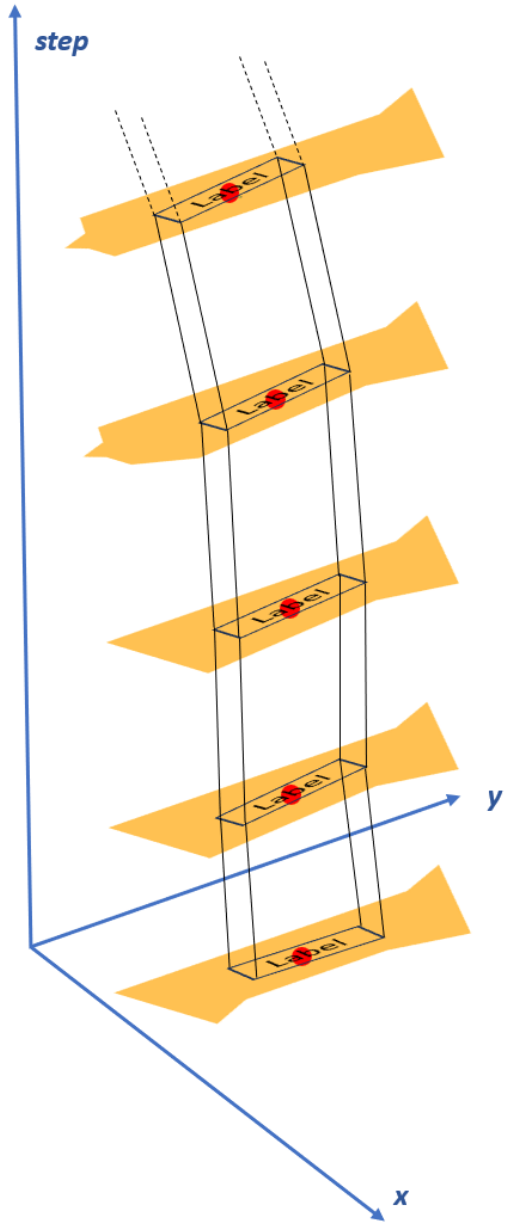


Polygonization from tGAP - Event-based Method



Label Lines Trajectory

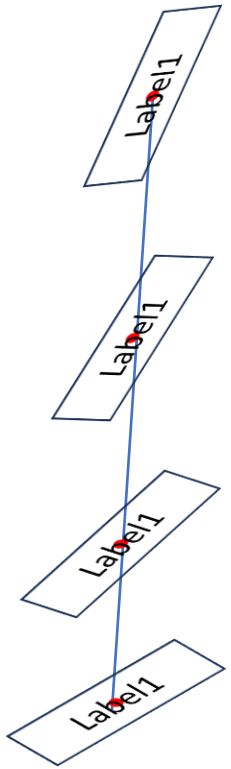
A moving label over space:
(x, y, angle, step)



Visualization - Interpolation of Labels

Given a label's position at two consecutive step, linearly **interpolate** its position and rotation angle.

When it's past *the last defined key step* but before the label's step_high: let labels **fade out**.

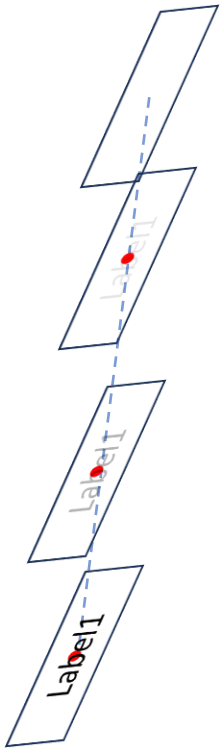


step=3(computed rotation and angle)

step=2(interpolated position and angle)

step=1(interpolated rotation and angle)

step=0(computed rotation and angle)



step_high = 6(when the face disappears, opacity = 0)

step=5(interpolated opacity)

step=4(interpolated opacity)

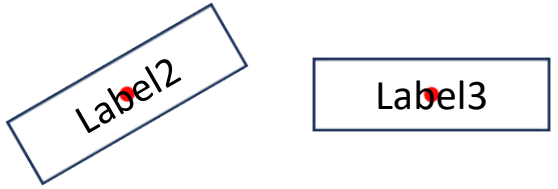
step=3(opacity = 1)

Visualization - Label Collision Detect

face1 step_high = 2000
face2 step_high = 1000

face1 stays longer, thus label1 is preferred

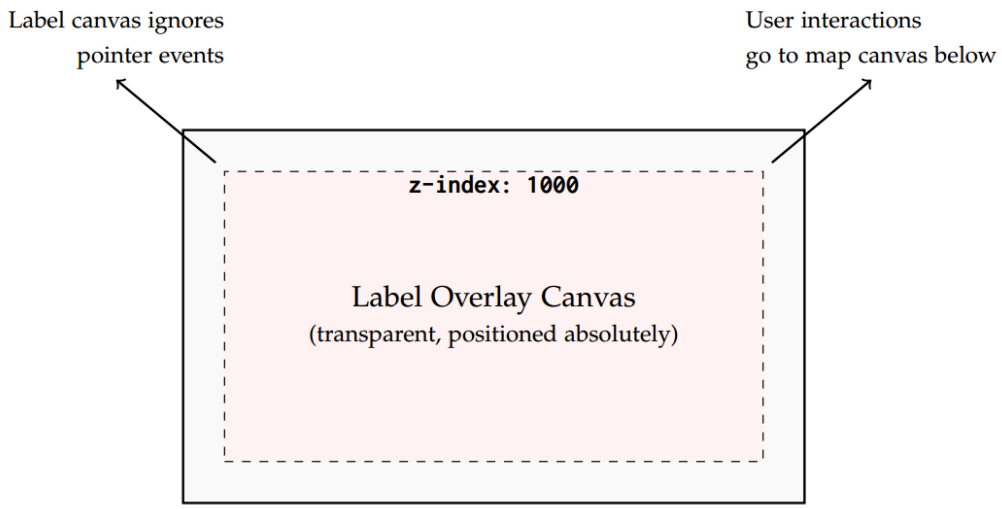
face1 step_high = 2000
face2 step_high = 2000



Label2 has shorter text, when face step_high is the same, label 2 is preferred

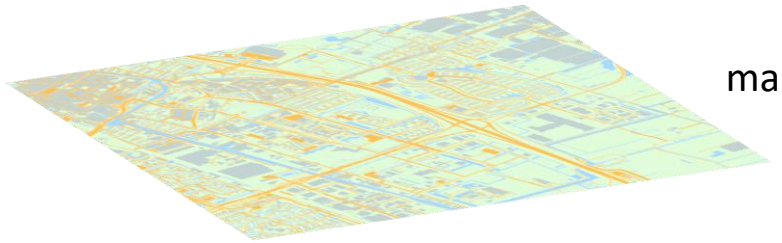
Visualization - Combining Text with the Underlying Map

The label overlay canvas is positioned above the map canvas using absolute positioning and a high z-index. It is transparent and ignores pointer events, allowing user interaction to reach the map layer underneath.



Every animation frame the map calls for update:
convert label world coordinates to screen coordinates;
get current scale denominator and calculate it into current step.

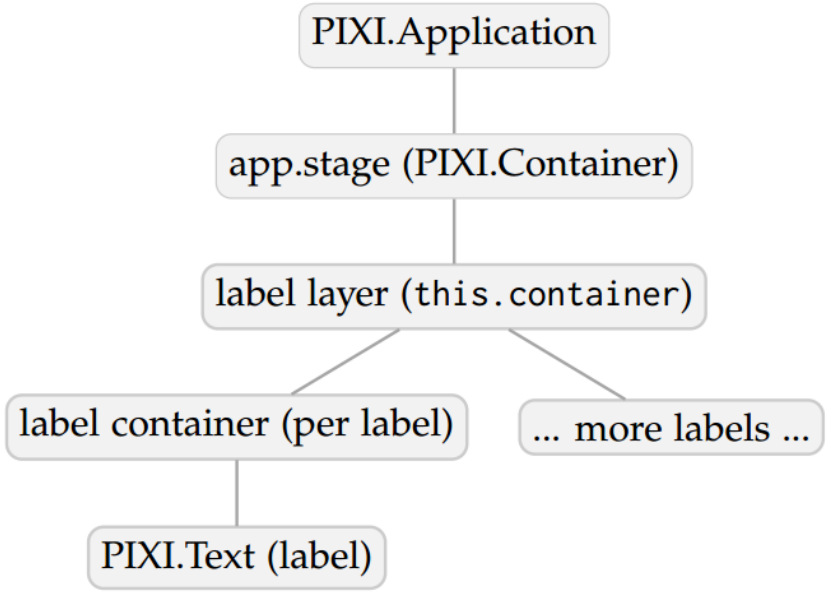
label canvas



map canvas

Visualization - Text Rendering

PixiJS - a high-performance 2D WebGL based renderer



PixiJS scene graph structure for dynamic label rendering

Visualization - Animation After Zooming Stops

Detecting zoom activity

mouse/touch

Detecting when zoom becomes idle

If the time exceeds a specified threshold, the map is considered idle

Starting and updating opacity animation

labels with opacity less than 1.0 gradually fade in

Resetting when zoom resumes

If the user starts zooming again during the fade-in process, the animation is cancelled

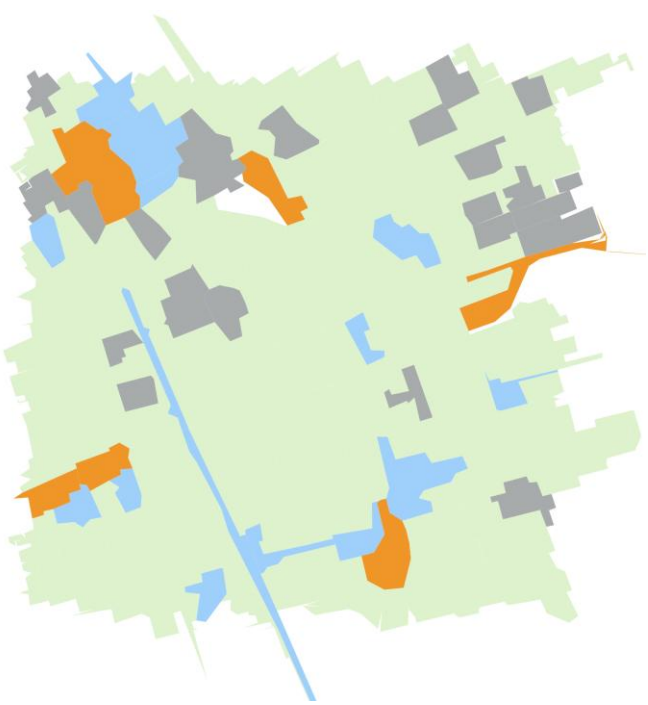
Let’s apply the methodology to Delft region!

Slice-based Method Result

scale=1:10,000 step=0

scale=1:20,000 step=9084

scale=1:40,000 step=11355

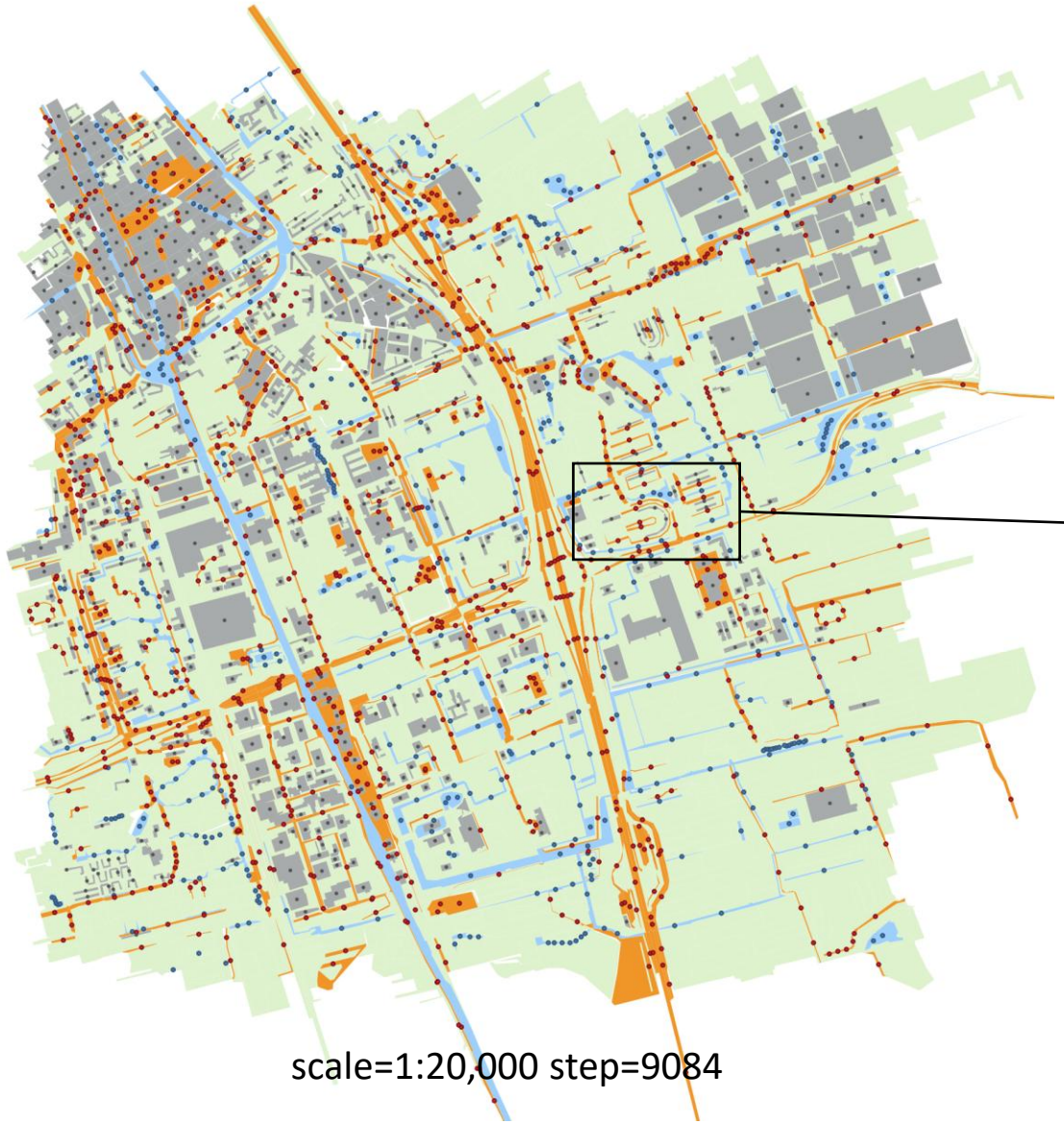


scale=1:80,000 step=11923

Slice-based Method Result

scale=1:10,000 step=0

Slice-based Method Result

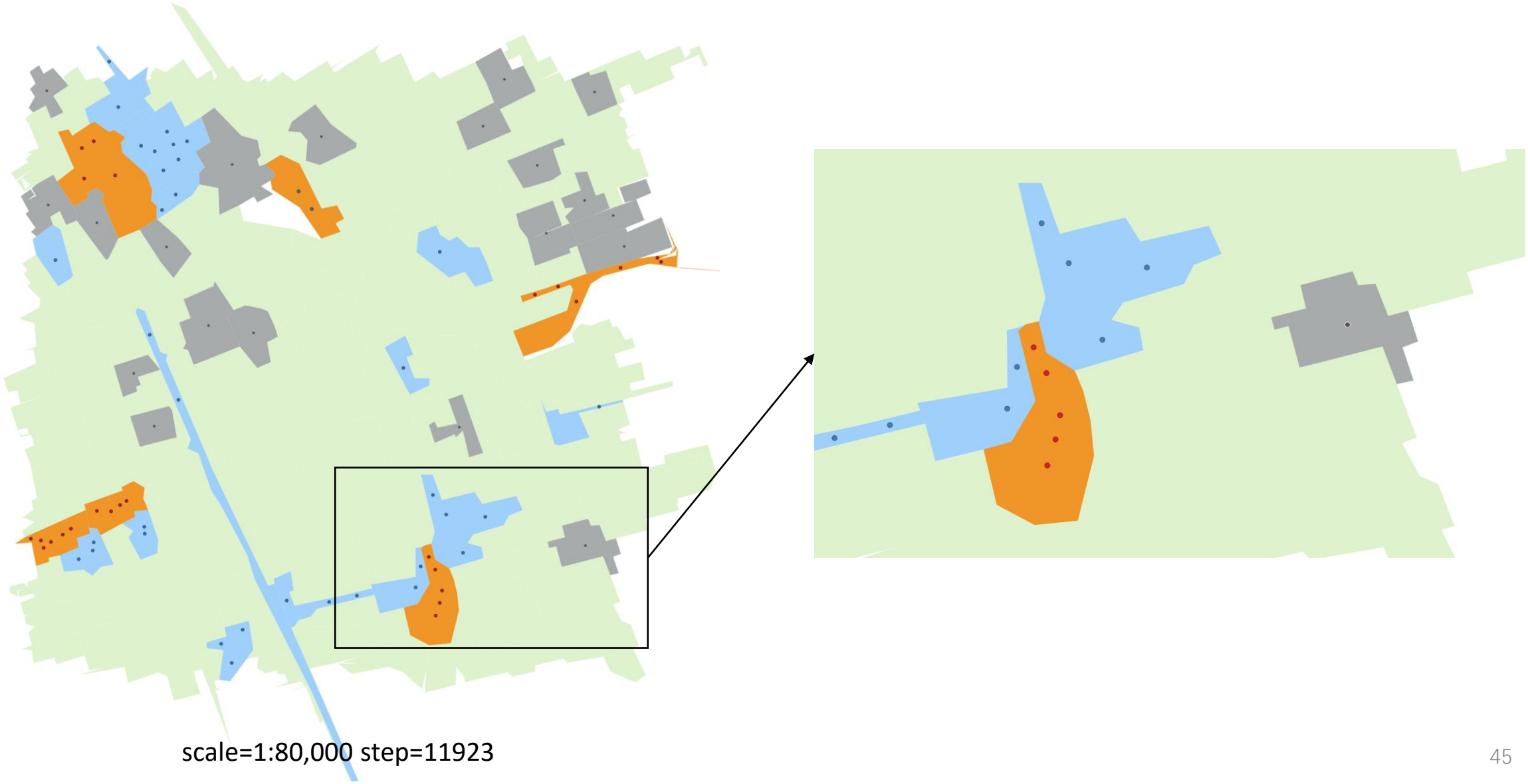


scale=1:20,000 step=9084

Slice-based Method Result

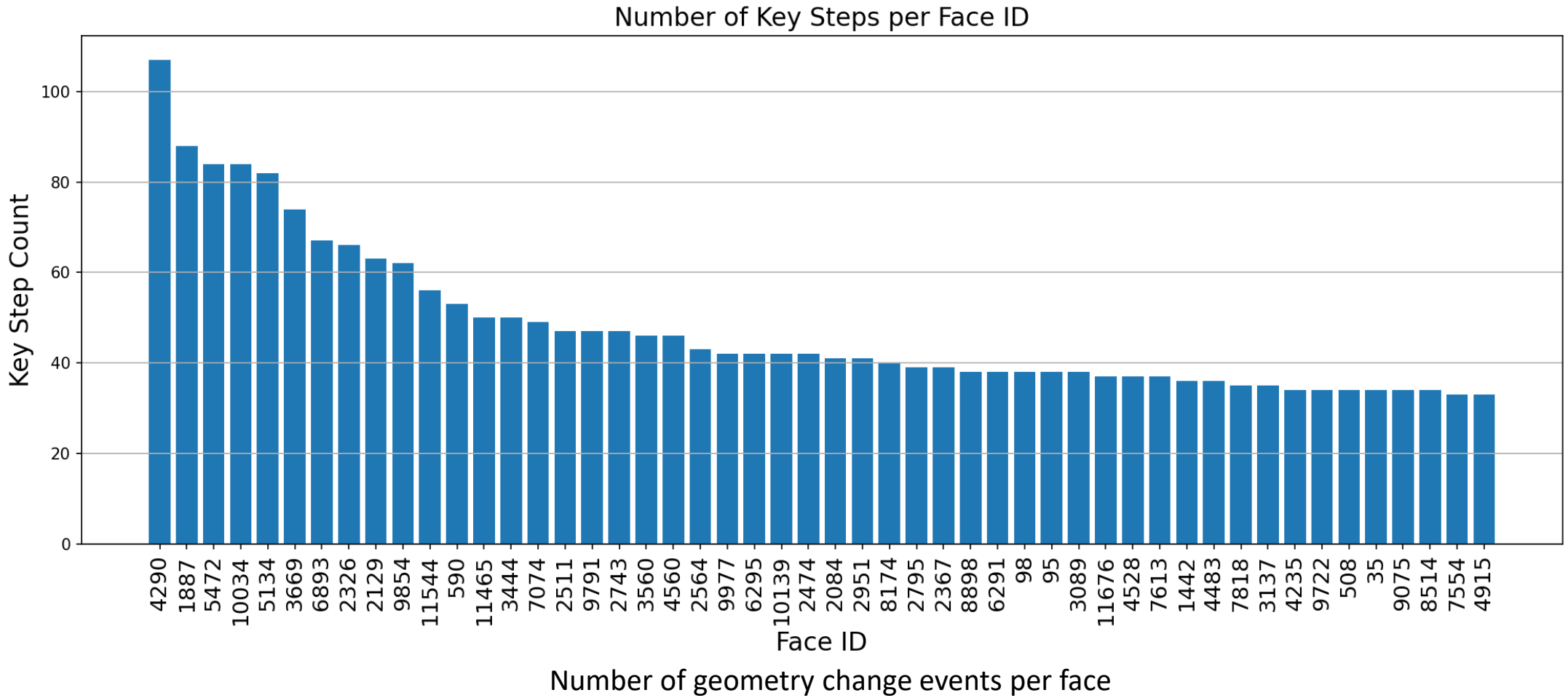
scale=1:40,000 step=11355

Slice-based Method Result



scale=1:80,000 step=11923

Event-based Method Result



Event-based Method Result

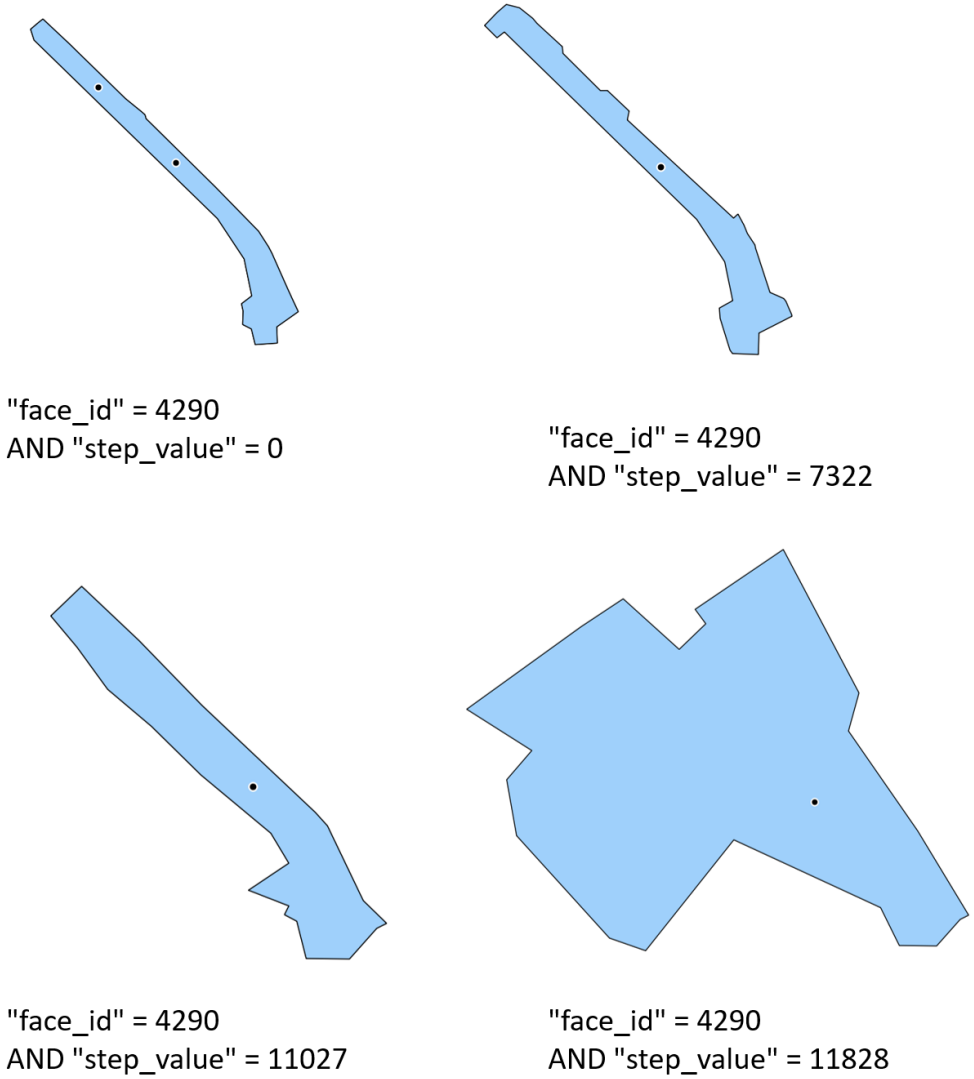


Figure. Geometry changes of face 4290

Comparison Between Two Methods

Slice-based: **12,974** anchor records
Event-based: **49,018** anchor records

Anchor positions were densified via linear interpolation to obtain positions at every intermediate scale step:

Method	Mean	p99	Max
Event-based	0.002	0.026	**216.715**
Slice-based	0.002	0.025	0.506

Figure. Anchor displacement due to geometry change in one face

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Event-based method: most of the time, labels have spatial stability; however, when a geometry event does occur, the recalculated anchor may differ significantly

Slice-based method: ensures continuity, but the label is forced to move gradually even if the underlying geometry remains unchanged

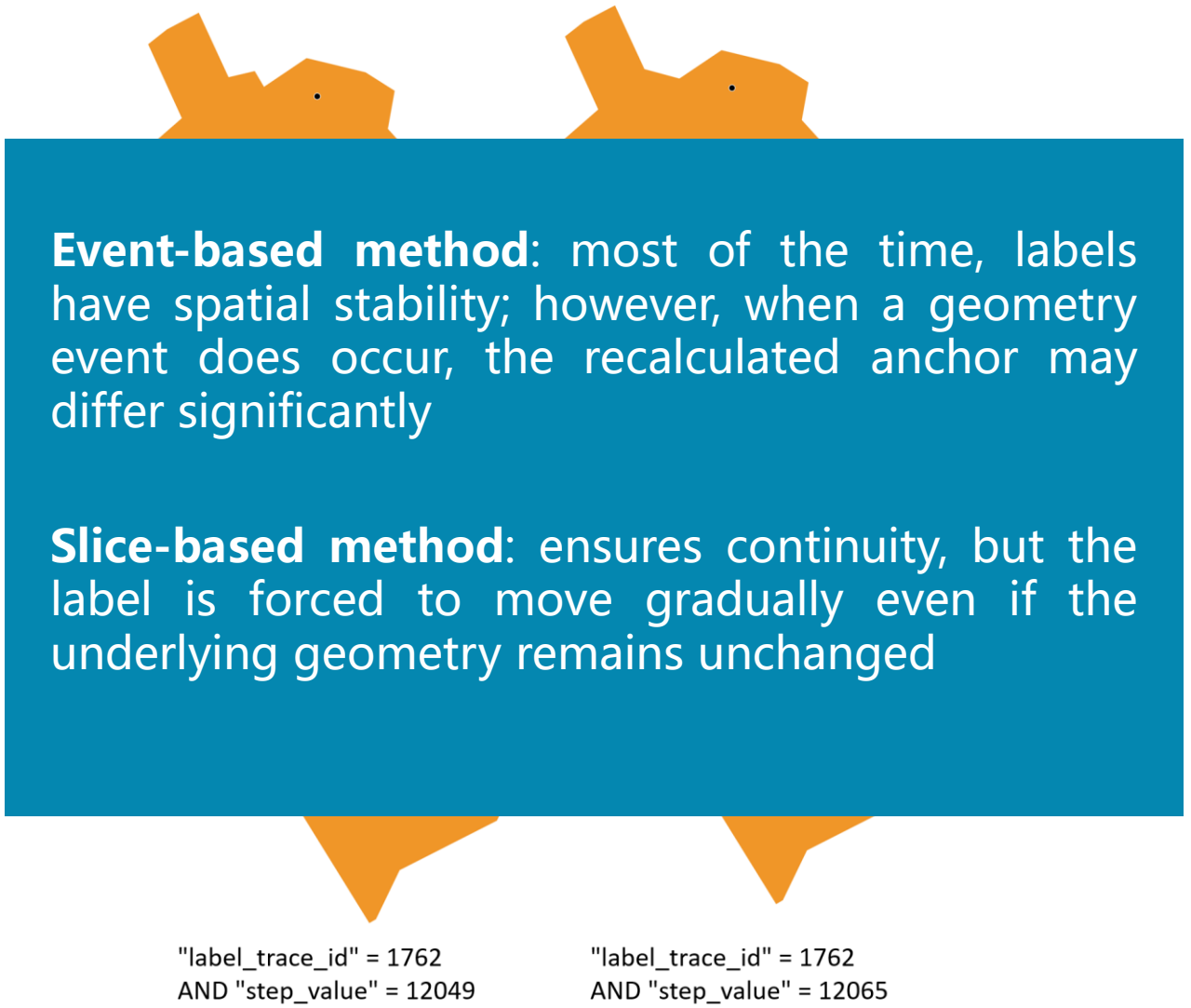
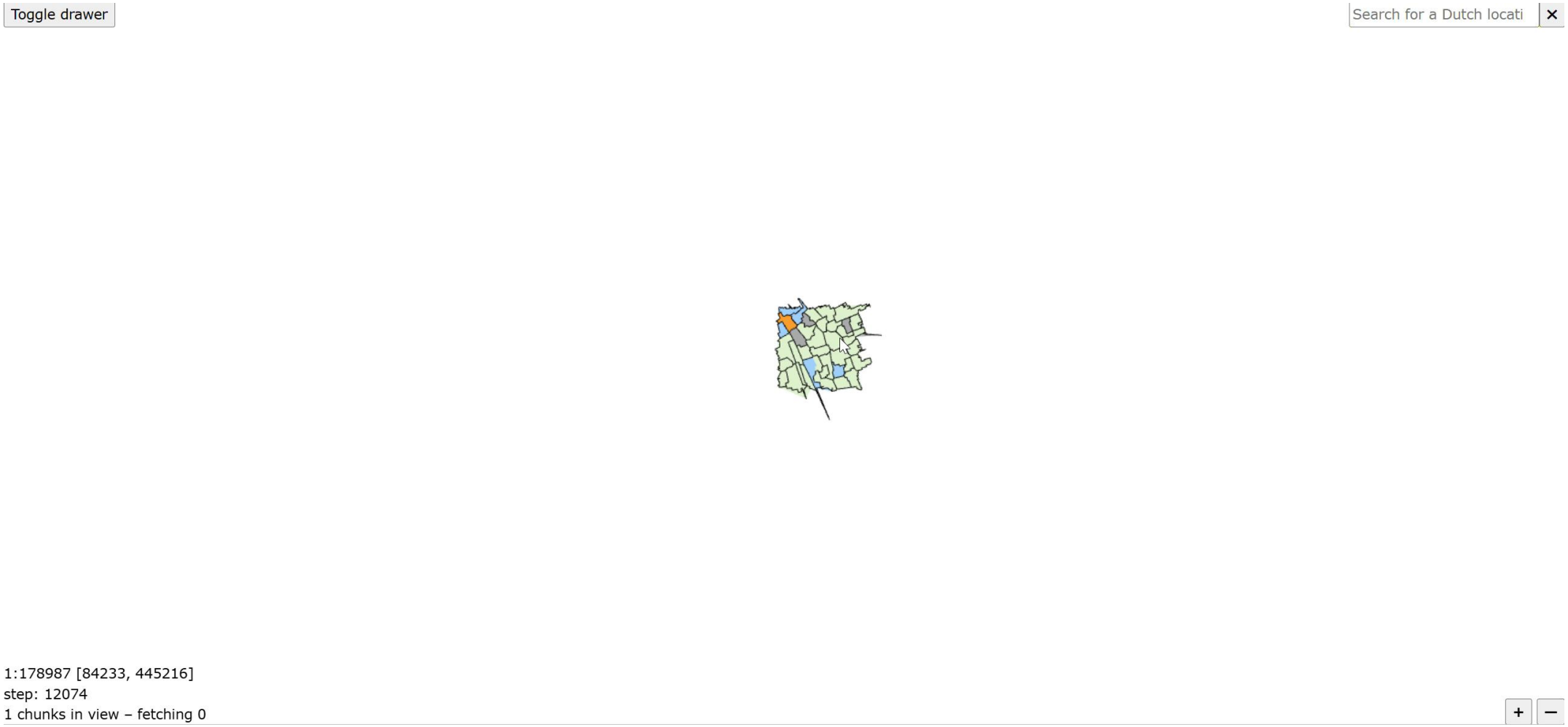


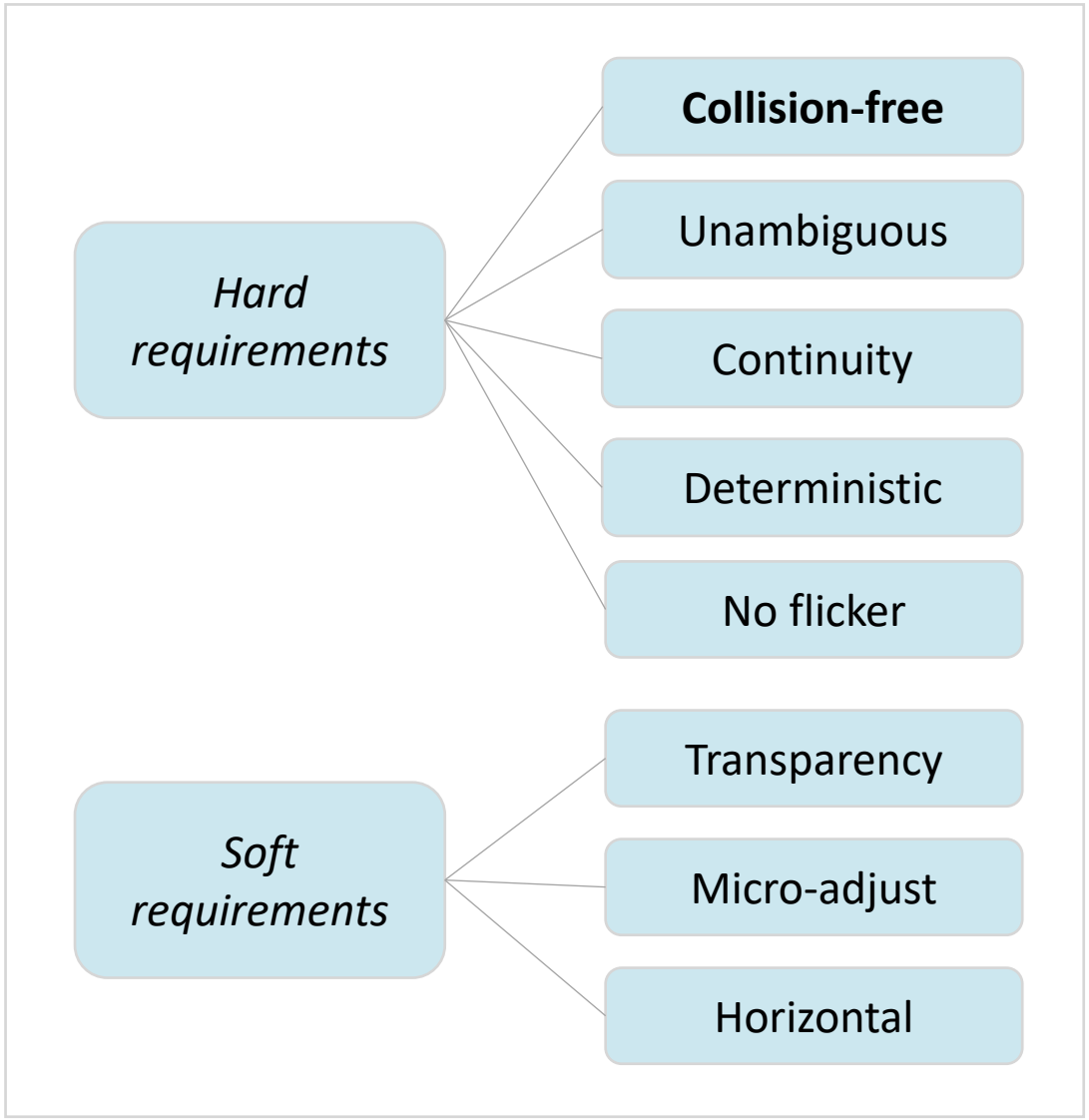
Figure. Anchor displacement due to geometry change in one face

Label Visualization Result

https://imyangao.github.io/Vario-scaleMapLabelingDemo/

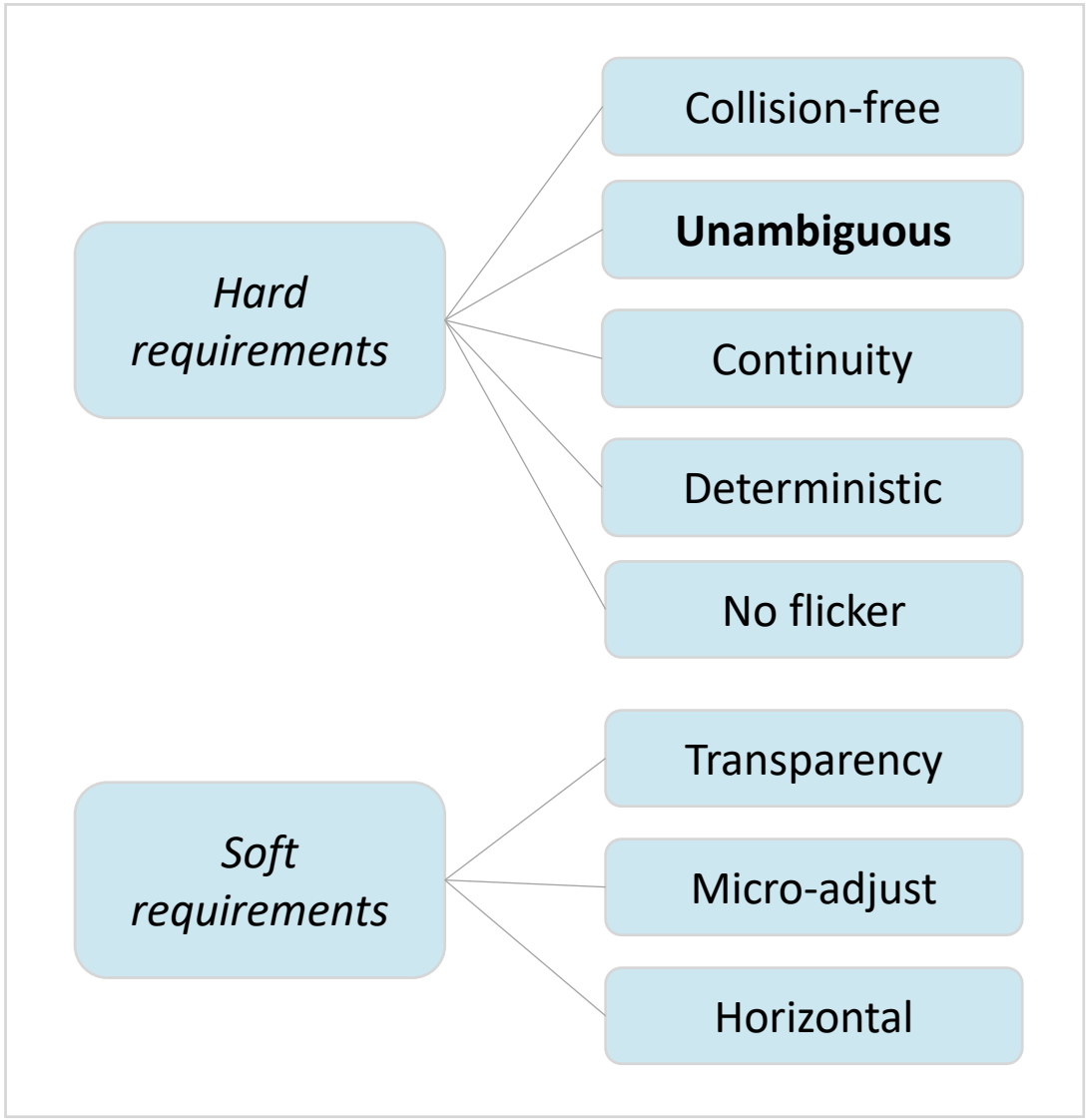


Evaluation of Label Placement Requirements



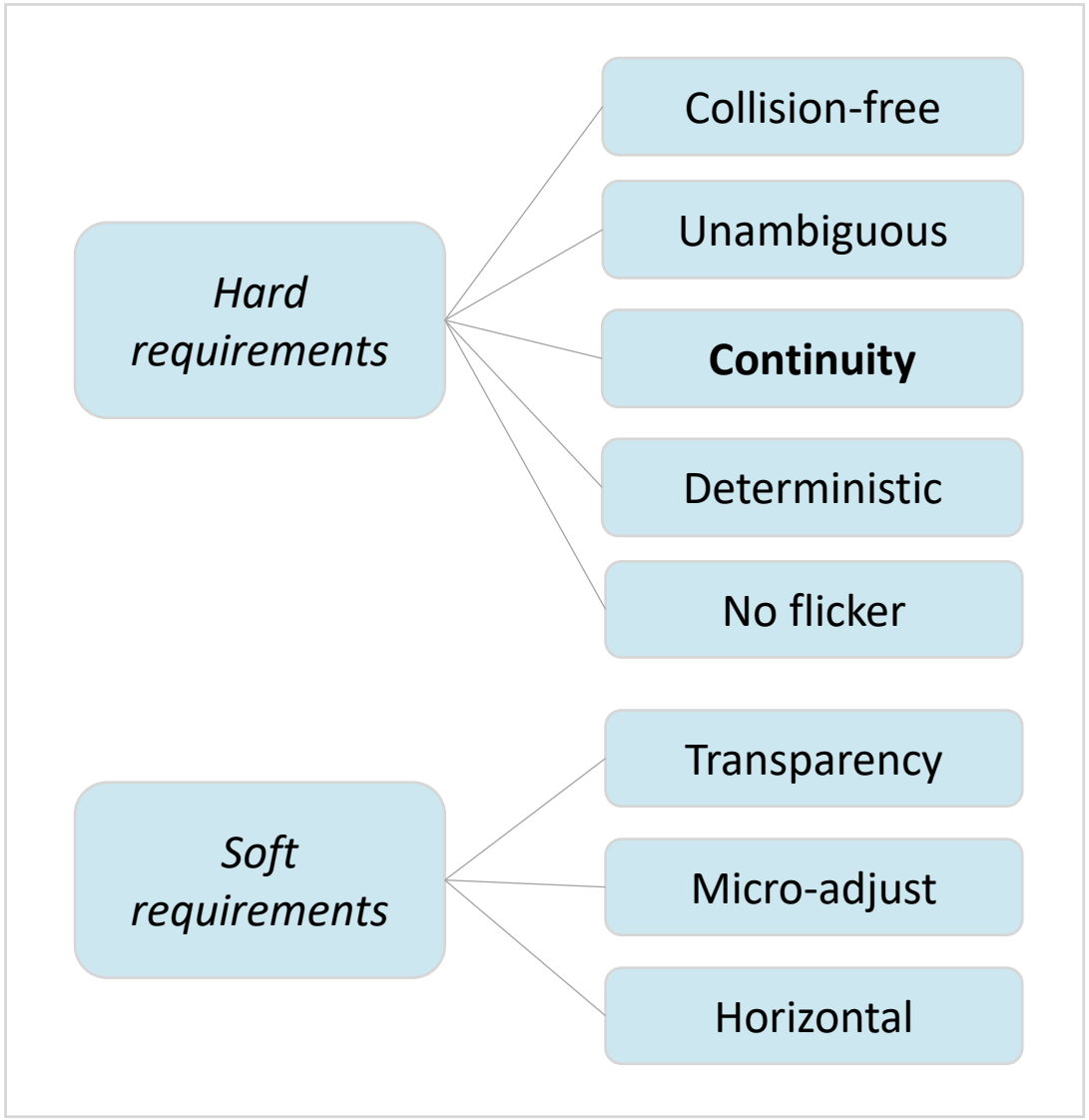
- ✓ the greedy collision detection algorithm combined with Rtree acceleration ensures no labels overlap at any visible scale.

Evaluation of Label Placement Requirements



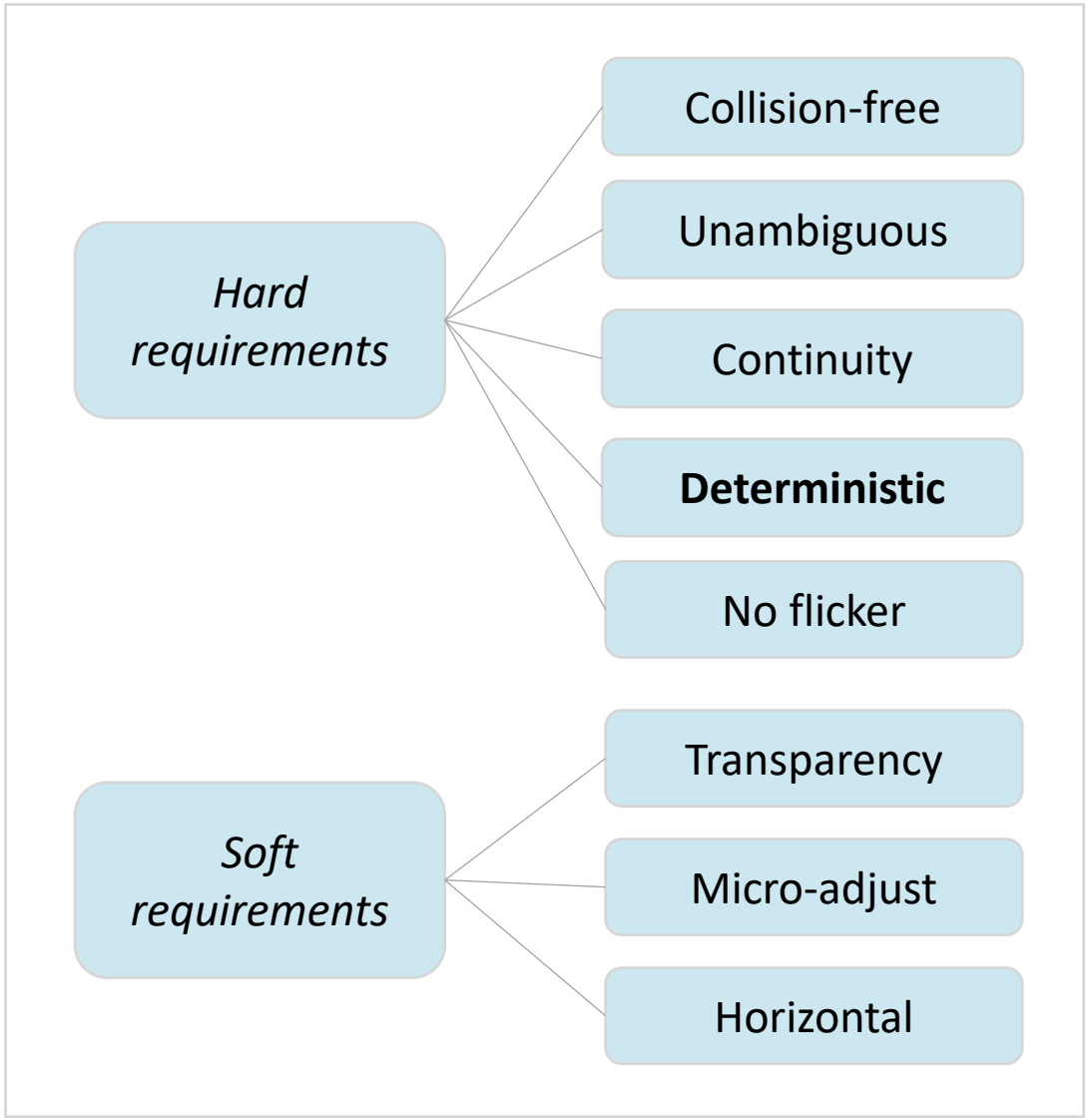
- ✓ each label is explicitly linked to a single feature through precise anchor placement methods.

Evaluation of Label Placement Requirements



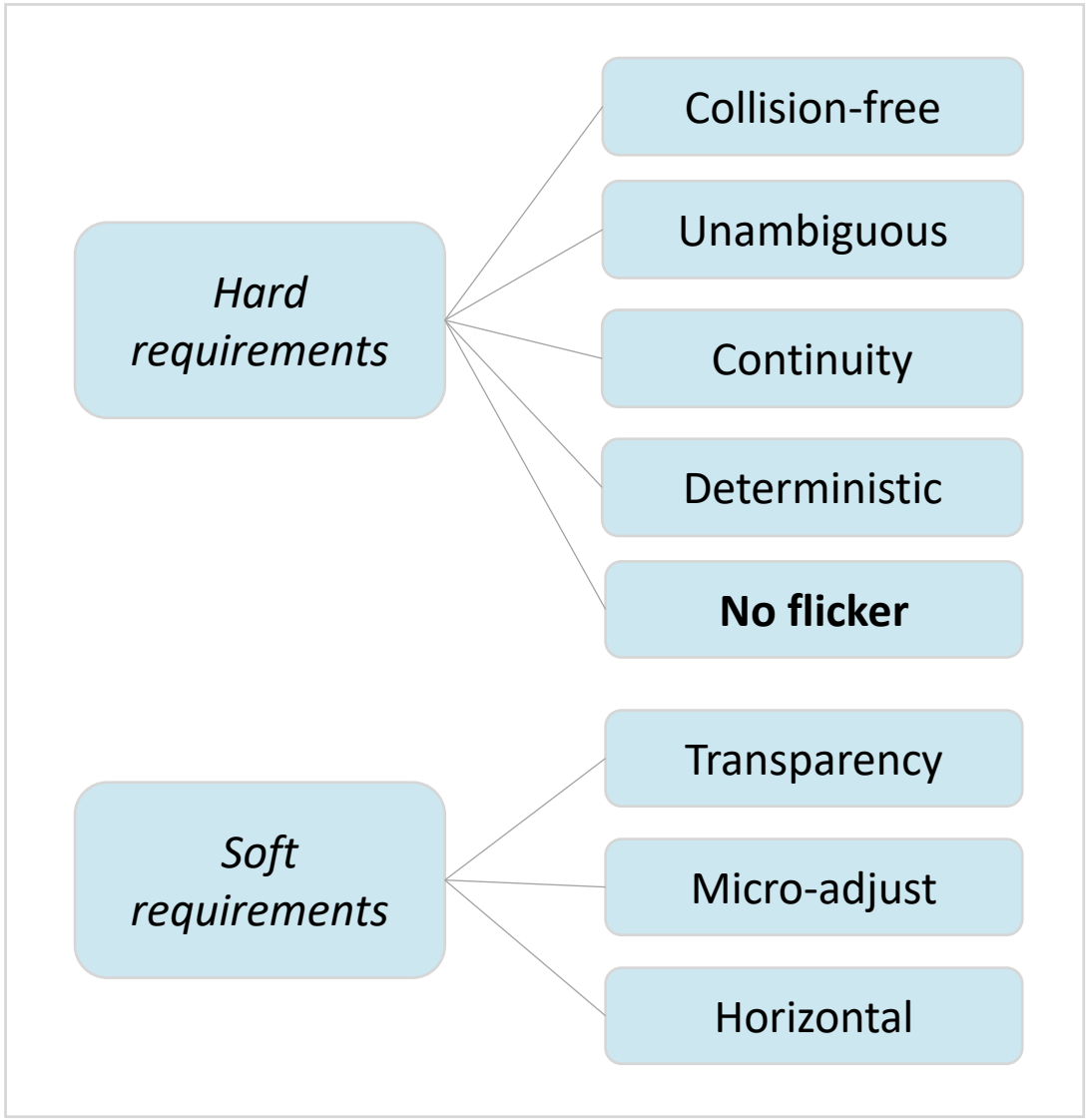
✓ the interpolation-based method provides smooth transitions of label position, rotation, and opacity between discrete scale steps.

Evaluation of Label Placement Requirements



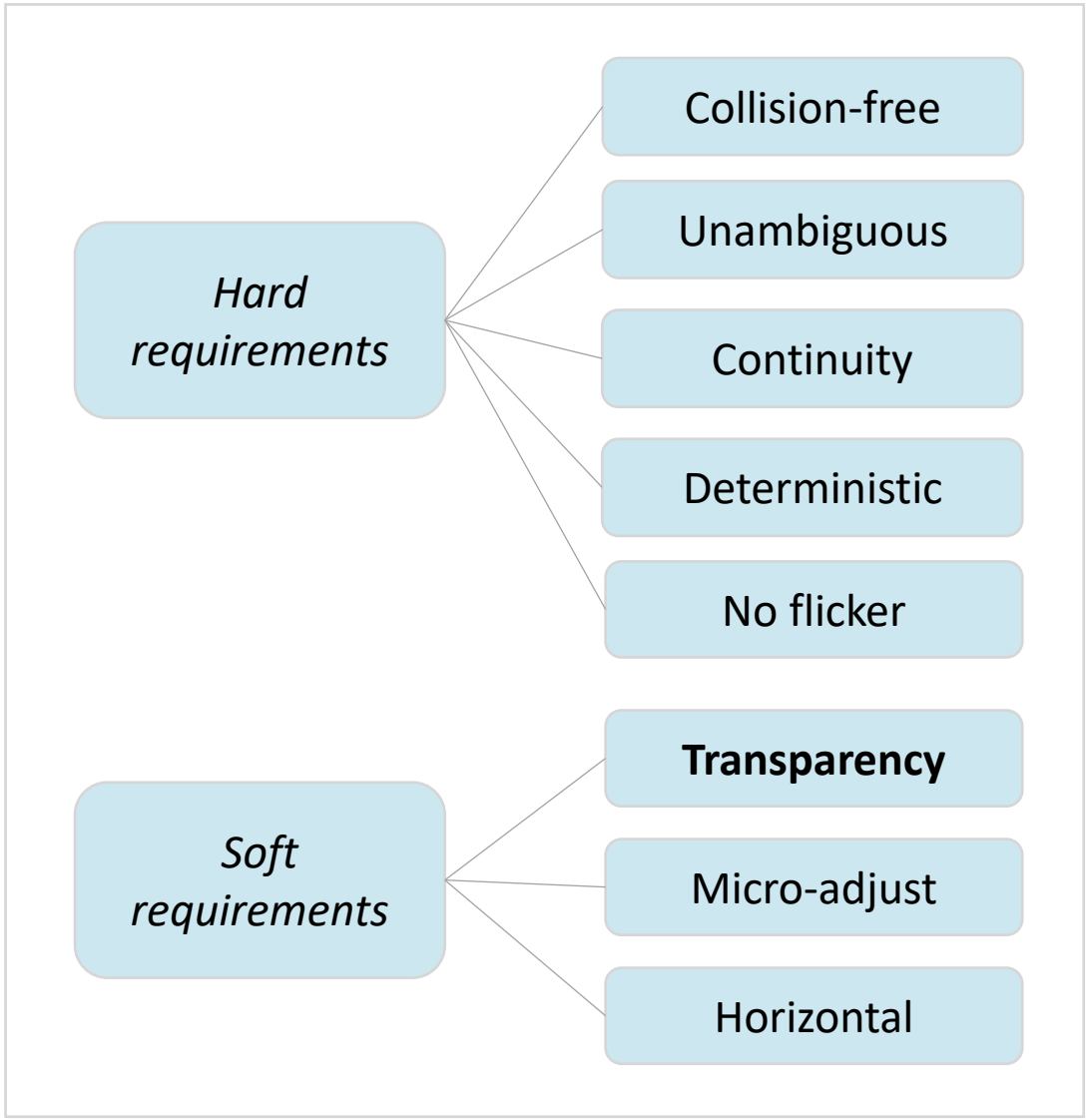
- ✓ labels are prioritized using a deterministic rule based on the step high value and text length.

Evaluation of Label Placement Requirements



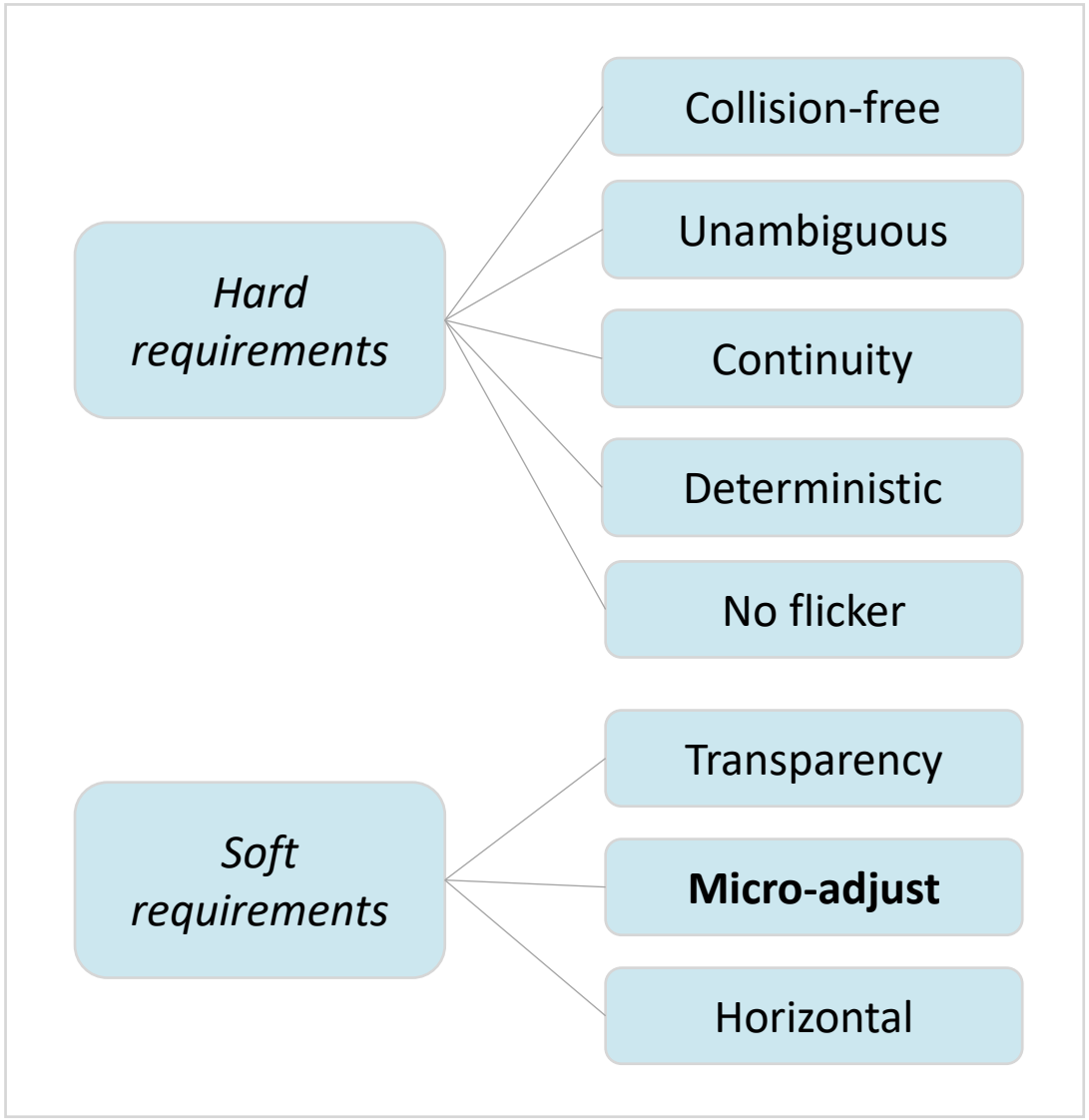
- when collision detection is performed on a per-frame basis, labels that appear in one frame may be removed in the next, leading to an undesirable flickering effect.

Evaluation of Label Placement Requirements



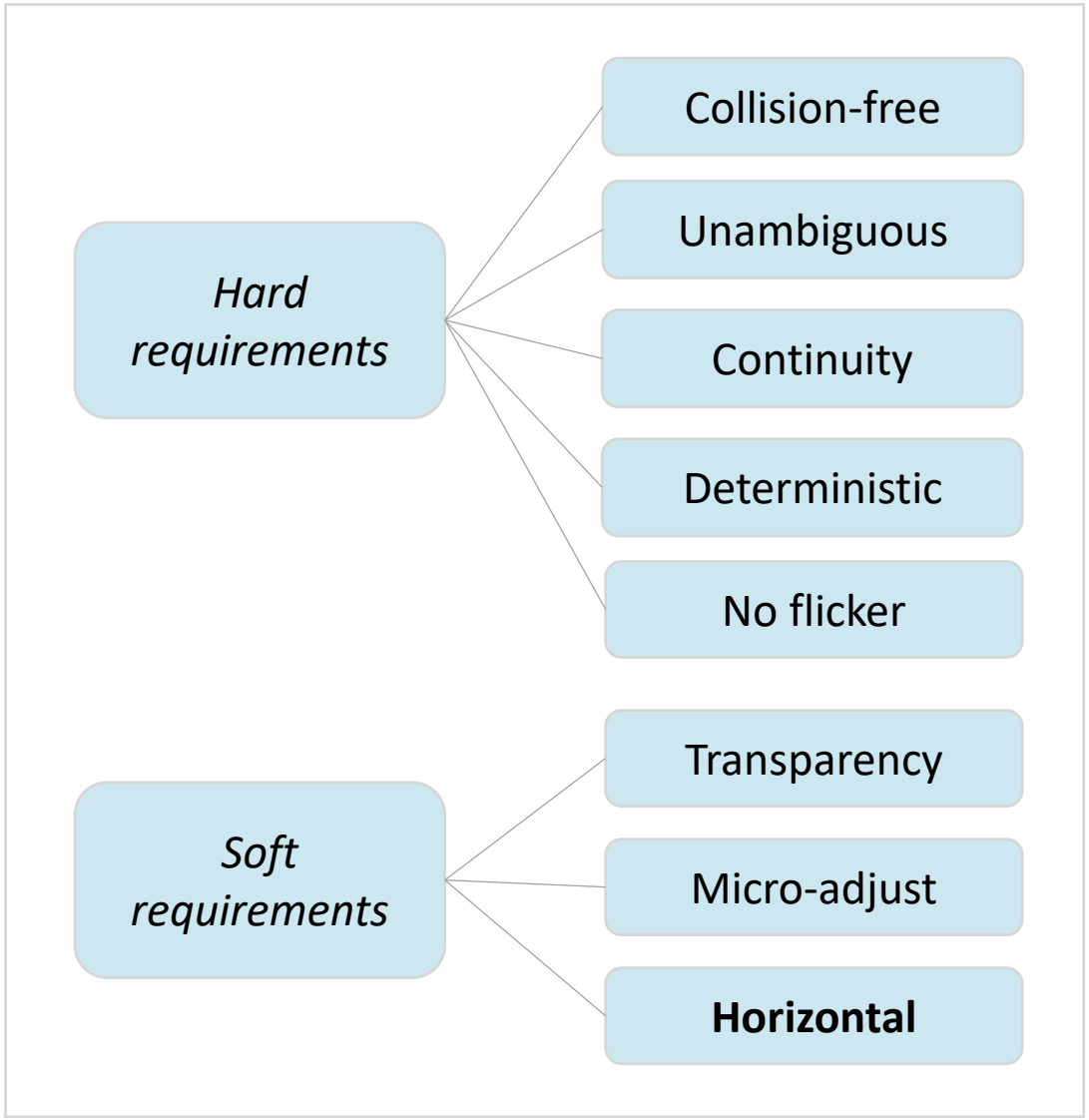
- ✓ an animation is applied once zooming stops, ensuring that labels reach full opacity in their final state.

Evaluation of Label Placement Requirements



× although this could increase label density, it adds large computational overhead and could negatively affect real-time performance.

Evaluation of Label Placement Requirements



✓ building labels are deliberately rendered with a fixed horizontal orientation.

Research Overview

Main Question

How can labels be dynamically placed and adjusted on vario-scale maps to maintain readability, usability, and visual coherence across continuously changing scales?

Sub Q1	Sub Q2	Sub Q3	Sub Q4	Sub Q5
Label placement requirements	Optimal placement techniques	Dynamic adjustments	Data structure and retrieval	Dynamic display

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Contributions

1. **Novel integration method**: new method was introduced for combining dynamic label transitions with the vario-scale tGAP data structure, supporting label continuity and smoothness during scale transitions.

2. **Anchor-based trajectory approach**: the concept of persistent label trajectories derived from anchor points was implemented, improving label continuity and visual coherence.

3. **Practical visualization approach**: developed an interactive visualization solution that demonstrated real-time smooth transitions and effective collision avoidance. The system is integrated with the underlying vario-scale base maps, ensuring alignment during panning and zooming.

Future Work

1. 3D skeletonization
2. Interpolation methods
3. Dynamic data transmission
4. Collision management
5. Integration into generalization processes
6. Support for additional interactions and features

References

- V. Agafonkin. polylabel: A fast algorithm for finding the pole of inaccessibility of a polygon. https://github.com/mapbox/polylabel, 2024.
- M. Barrault. A methodology for placement and evaluation of area map labels. Computers, Environment and Urban Systems, 25(1):33–52, 2001. doi: 10.1016/s0198-9715(00)00039-9.
- M. Barrault and F. Lecordix. An automated system for linear feature name placement which complies with cartographic quality criteria. In AUTOCARTO-CONFERENCE-, pages 321–330, 1995.
- K. Been, E. Daiches, and C. Yap. Dynamic map labeling. IEEE Transactions on Visualization and Computer Graphics, 12(5):773–780, 2006. doi: 10.1109/tvcg.2006.136.
- K. Been, M. Nollenburg, S.-H. Poon, and A. Wolff. Optimizing active ranges for consistent dynamic map labeling. Computational Geometry, 43(3):312–328, 2010. ISSN 0925-7721. doi: https://doi.org/10.1016/j.comgeo.2009.03.006. URL https://www.sciencedirect.com/science/article/pii/S0925772109000649. Special Issue on 24th Annual Symposium on Computational Geometry (SoCG'08).
- S. Biniek, G. Touya, and G. Rouffineau. Fifty shades of roboto: Text design choices and categories in multi-scale maps. Advances in Cartography and GIScience of the ICA, 1:1–8,2019. doi: 10.5194/ica-adv-1-2-2019.
- D. Dorschlag, I. Petzold, and L. Pl ¨ umer. Placing objects automatically in areas of maps. 01 2003.
- S. Edmondson, J. Christensen, J. Marks, and S. Shieber. A general cartographic labelling algorithm. Cartographica, 33(4):13–24, 1996. doi: 10.3138/U3N2-6363-130N-H870. URL https://doi.org/10.3138/U3N2-6363-130N-H870.
- O. Ertz, M. Laurent, D. Rappo, A. Sae-Tang, and E. Taillard. Pal-a cartographic labelling library. 01 2008.
- D. Garcia-Castellanos and U. Lombardo. Poles of inaccessibility: A calculation algorithm for the remotest places on earth. Scottish Geographical Journal, 123(3):227–233, 2007.
- C. Green. Improved alpha-tested magnification for vector textures and special effects. In ACM SIGGRAPH 2007 Courses, SIGGRAPH '07, page 9–18, New York, NY, USA, 2007. Association for Computing Machinery. ISBN 9781450318235. doi: 10.1145/1281500.1281665. URL https://doi-org.tudelft.idm.oclc.org/10.1145/1281500.1281665.
- E. Imhof. Positioning names on maps. The American Cartographer, 2(2):128–144, 1975. doi: 10.1559/152304075784313304.
- G. W. Klau and P. Mutzel. Optimal labeling of point features in rectangular labeling models. Mathematical Programming, 94(2-3):435–458, 2003. doi: 10.1007/s10107-002-0327-9.

References

- I. Pinto and H. Freeman. The feedback approach to cartographic areal text placement, volume 1121, pages 341–350. 01 2006. ISBN 978-3-540-61577-4. doi: 10.1007/3-540-61577-6 35.
- N. Schwartges. Dynamic Label Placement in Practice. doctoralthesis, Universitat Wurzburg, 2015.
- T. Strijk and M. Kreveld. Practical extensions of point labeling in the slider model. GeoInformatica, 6, 03 2000. doi: 10.1023/A:1015202410664.
- M. van Kreveld, T. Strijk, and A. Wolff. Point labeling with sliding labels. Computational Geometry, 13(1):21–47, 1999. ISSN 0925-7721. doi: https://doi.org/10.1016/S0925-7721(99)00005-X. URL https://www.sciencedirect.com/science/article/pii/S092577219900005X.
- P. van Oosterom and B. Meijers. Towards a true vario-scale structure supporting smoothzoom. In D. Burghardt and M. Sesters, editors, Proceedings of the 14th Workshop of the ICA Commission on Generalisation and Multiple Representation the ISPRS Commission II/2 Working Group on Multiscale Representation of Spatial Data: Geographic Information on Demand, pages 1–19, 2011.
- P. van Oosterom and B. Meijers. Vario-scale data structures supporting smooth zoom and progressive transfer of 2D and 3D data, pages 21–42. Nederlandse Commissie voor Geodesie -KNAW, 2012a. ISBN 978-90-6132-339-6.
- P. van Oosterom and B. Meijers. True vario-scale maps that support smooth-zoom. In K. de Zeeuw, editor, S.n., pages 1–9. Geospatial World Forum, 2012b. Geospatial World Forum - Theme: Geospatial Industryt and World Economy (Amsterdam, The Netherlands) ; Conference date: 23-04-2012 Through 27-04-2012.
- J. W. van Roessel. An algorithm for locating candidate labeling boxes within a polygon. 16(3):201–209, 1989. doi: 10.1559/152304089783814034.
- A. Wolff, L. Knipping, M. van Kreveld, T. Strijk, and P. Agarwal. A simple and efficient algorithm for high-quality line labeling, volume 2001-44. Utrecht University: Information and Computing Sciences, uu-cs edition, 2001. ISBN 0924-3275.