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Research Article

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Posted Date: September 9th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10523474/v1

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Visualizing Change in Choropleth Maps: Influence of Spatial Discretization and Interactive Comparison Modes on Usability

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Abstract: Map comparison is a fundamental step to geographic inquiry, enabling users to detect spatiotemporal changes and identify spatial correlations. Several comparative layouts exist, but their effectiveness is limited by visual change blindness and data presentation formats. This study examines the interplay between two comparative layouts (i.e. side-by-side juxtaposition and slider-based transition) and spatial discretization geometries (hexagonal and square grids, and irregular administrative polygons) over three levels of complexity. We conducted a user experiment with 39 participants (N = 344 trials) logging response times and error rates. Results show that slider-based transition significantly improves efficiency in high-complexity visual search tasks. However, performance varied across task complexity: side-by-side juxtaposition showed better accuracy in low-complexity tasks. Spatial discretization geometry has acted as an essential mediator: hexagonal grids outperformed irregular polygons both in response time and error reduction. Hence, comparative layout efficacy cannot be evaluated in isolation, but is bound to the underlying spatial aggregation geometry.

Keywords: Map comparison, Comparative layouts, Spatial discretization, Choropleth maps, Usability, Change blindness

1. Introduction

Comparison, seen from an epistemological perspective, is not just a method of scientific inquiry, but a fundamental cognitive operation through which human understanding is generated. As classical philosophy demonstrates—e.g., John Locke's assertion that the human mind "cannot look on any thing, without looking, as it were, beyond it, to see what it has connection with" (Locke, 1690/1894)—we cannot perceive structure without evaluating relations.

In cartography, this principle manifests across three dimensions:

- *User perspective*: Map comparison is a cornerstone of geographic analysis, as the value of spatial data often lies in the relationship between multiple datasets rather than in a single isolated view. Primarily, it serves as the essential mechanism for spatiotemporal analysis, enabling users to detect changes and track trends over time (Long & Robertson, 2018; Visser & de Nijs, 2006). Beyond temporal shifts, comparison is vital for identifying spatial correlations, in order to uncover dependencies between different variables.

- *Technical standpoint*: Various techniques for visualizing changes both within and between maps have been developed over the last two centuries (cf. Friendly, 2008). While some of these approaches are designed for static or analog media, others depend on interactive digital manipulation. Given ongoing technological advancements, new visualization methods continuously emerge.
- *Empirical Perspective*: We can also compare how different interface layouts and map designs facilitate or complicate understanding on the user side. Here, adopting a meta-perspective on the technical standpoint, it is possible to compare techniques of visualizing change—in other words, to compare modes of map comparison. It is this empirical dimension regarding comparative layouts that the rest of this paper focuses on.

2. Theoretical Background and Related Work

2.1 Taxonomy of Comparative Layouts

The classification of comparative visualization designs has been a frequent subject of research in recent years. A general baseline for this discourse was established by Gleicher et al. (2011), who proposed three comparison primitives: juxtaposition, superposition, and explicit encoding—the latter referring to designs "where the relationships between objects are shown explicitly by providing a visual encoding of them."

However, L'Yi et al. (2021) argued that these broad categories might lead to ambiguous boundaries and inconsistent terminology, proposing an alternative classification of five distinct categories and one hybrid layout. While adhering to the original concepts of superposition and explicit encoding, they divide juxtaposition into chart-wise juxtaposition (e.g., placing two complete maps side-by-side) and item-wise juxtaposition (e.g., showing election results for 2020 vs. 2024 through bar-charts inside each municipality on a single thematic map). Their revised framework also incorporates animated transition (temporally separating visualizations within the same physical space) as its own category. Finally, they introduce hybrid layouts to account for complex designs combining multiple comparison methods simultaneously.

In this paper, we primarily rely on the taxonomy of L'Yi et al. (2021), from which two core types for comparing two maps M_A and M_B can be derived (fig. 1):

- Chart-wise juxtaposition (SBS): Represents the traditional standard employed in printed maps and side-by-side digital viewports.
- Animated transition (SL): Enables interactive comparison within digital formats, such as slider-based swipe interfaces.

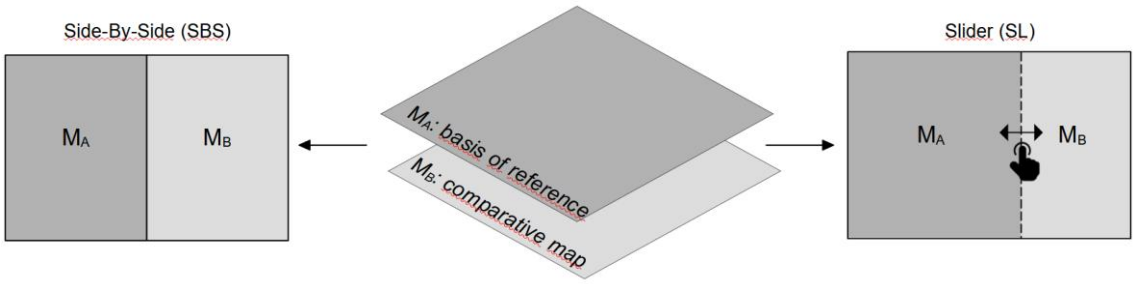


Fig. 1. Conceptual overview of the two tested map comparison idioms derived from the taxonomy of L'Yi et al. (2021): juxtaposition (side-by-side, SBS) on the left, and interactive animated transition (slider, SL) on the right, operating over two maps (M_A and M_B).

The remaining elements of the taxonomy established by L'Yi et al. (2021) are of minor concern for this study due to specific cartographic constraints: Explicit encoding contradicts the principle of comparing two distinct maps, as the visualization of change occurs entirely within a single map view; superposition of two complete maps is logically unfeasible without complete occlusion or transitioning into explicit encoding via layer blending; finally, hybrid layouts (though accurately describing many complex thematic map designs) do not constitute a distinct mode of comparing two separate map views.

2.2 Visual Perception

Inherent to comparison tasks is the tendency for change blindness, whereby changes to a display go undetected as attention is diverted from the scene (Rensink, 2002). Within cartographic interfaces, this cognitive limit depends on whether comparison layouts separate information across space (juxtaposition/SBS) or across time (animated transition/SL).

When using juxtaposition, separating information in space puts considerable stress on human vision. Eye-tracking and behavioral observations show that side-by-side layouts force users to continuously shift their focus back and forth between viewports (Tominski et al., 2012). Observers cannot compare two states concurrently; instead, they must retain a mental image of the first map and then compare it to the second, leading to a cognitive load and long scan paths (Plumlee & Ware, 2006). This memory load is why side-by-side maps are inefficient for detecting complex visual stimuli and subtle difference detection (Sambasivan et al., 2013).

To eliminate the effects of distance, animated transitions uses identical physical screen coordinates (cf. fig. 1). One visualization space is continuously changing, which facilitates object constancy and provides a natural way for viewers to track data transformations (Heer & Robertson, 2007). By aligning comparison targets in the same location, an interactive slider uses the visual system’s sensitivity to motion to create flicker and allow local changes to pop out (Ondov et al., 2019). However, the efficacy of animated transitions is sensitive to visual complexity. Because the visualizations are separated in time, users cannot perform stable

concurrent verification (Munzner, 2015). If the underlying spatial structure changes drastically, animation may confuse the observers, leading to decreased accuracy (Sambasivan et al., 2013).

2.3 Geometric Influence

On a spatial statistical level, data aggregation leads to the Modifiable Areal Unit Problem (MAUP; Openshaw, 1983). Changing spatial aggregation at different scales or boundaries yields vastly different visual outcomes, while arbitrary zonal boundaries can mask individual characteristics, thus creating fallacies (Robinson, 1950) and manipulating perceived spatial patterns.

This adds to the uncertainty linked to area-size bias (Dent, 1999; Speckmann & Verbeek, 2010): Because larger spatial units are visually heavier, users tend to neglect smaller geographic regions (Schiewe, 2019). Cartographers often seek visual equalization by using regularized geometries, such as hexagonal tessellations, to achieve visual equalization (Slocum et al., 2009). Regularized grids also help preserve the mental map during transitions (Forsch et al., 2024), but their actual effectiveness when combined with interactive comparison tools remains to be empirically tested.

2.4 Synthesis and Research Justification

Despite advancements in comparative visualization, empirical findings regarding the optimal map comparison layouts remain inconclusive. For example, while animated transitions outperformed the static side-by-side layout in local change detection (Svicarovic et al., 2021; Ondov et al., 2019), global trend detection was sometimes more accurate with juxtaposition due to the lower cognitive load (Jardine et al., 2019; Lobo et al., 2015; Naragino & Misue, 2017; Popelka et al., 2022). Besides, layout effectiveness varies significantly across visual representations and environmental conditions (L'Yi et al., 2021).

We fill this critical gap by testing a key environmental variable: spatial discretization. While information visualization research deals mostly with abstract charts, geographic mapping comes with specific constraints, like area-size bias (Schiewe, 2019) and mental map preservation (Forsch et al., 2024). Instead of looking for an inherently better geometry, our objective is to investigate how data aggregation —from regular hexagonal grids to irregular administrative polygons— affect the usability of static chart-wise juxtaposition versus an interactive animated slider at different levels of task complexity.

3. Methodology

This study investigates the impact of comparison modes and spatial discretization on user performance and usability metrics in choropleth maps. The general hypothesis is that animated

transition via slider (SL) reduces cognitive load and improves visual efficiency compared to side-by-side juxtaposition (SBS), particularly as the geometric complexity of the data layout increases. Comparative layout design (SL vs. SBS) and spatial discretization geometry are the independent variables.

We implemented a counterbalanced mixed design to control for cognitive fatigue without compromising layout coverage (cf. Kirk, 2013; L'Yi et al., 2021; Popelka et al., 2022). The SL and SBS interfaces were evaluated across hexagonal grids, square grids, and irregular administrative polygons with low, medium and high complexity levels. Visual efficiency (measured by response time in seconds) and precision (calculated by the number of errors) are the dependent variables.

3.1 Sample and Data Cleaning

N = 39 undergraduate students from the Berliner Hochschule für Technik (BHT), enrolled in the introductory GIS course, participated in the study. They were divided into two groups to fit the counterbalanced mixed design concept; each participant thus completed 9 tasks. From the theoretical maximum of (39*9=) 351 active trials, 7 trials were excluded due to incomplete coordinate logging or user-initiated browser interruptions, yielding N = 344 valid trials. An interquartile range (IQR) filter with a 1.5 multiplier fence was applied to eliminate extreme performance outliers resulting e.g. from temporary task abandonment or distractions.

3.2 Test Material

Spatial discretization geometries: To evaluate spatial structure effects, we used data from the 2024 Austrian National Council elections for Lower Austria municipalities and Vienna districts. The thematic context was not relevant for the usability test and kept neutral thus. The base dataset of 393 spatial objects was aggregated into:

- Irregular real-world administrative municipal/district boundaries (ADMIN).
- Uniform hexagonal grid structures (HEX).
- Uniform square grid structures (SQU).

Consequently, every stimulus map contained exactly 393 spatial reference units.

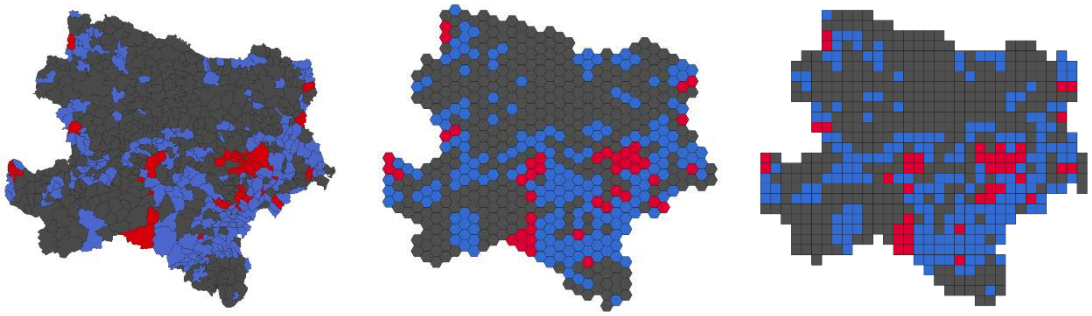


Fig. 2. Spatial discretization geometries used in the test apparatus, each containing exactly 393 spatial units: irregular administrative boundaries (ADMIN, left), hexagonal grid (HEX, middle), and square grid (SQU, right)

Task complexity profiles: To better understand user performance and usability metrics when comparing choropleth maps, a single target polygon within each of the three spatial discretization geometries was systematically manipulated to create an alternating comparison map. Three levels of difficulty thresholds based on the spatial layout characteristics were embedded within these data:

- Low Complexity (C_L): target features located centrally within large, homogeneous data clusters (Fig. 3a).
- Medium Complexity (C_M): target features located along regional cluster boundaries (Fig. 3b).
- High Complexity (C_H): target features located in an area with high visual noise and no clear spatial structure (fig. 3c).

In total, 9 pairs of comparison maps were compiled across these variables. Visual comparison was always evaluated within identical geometries—that is, comparing hexagonal grids against hexagonal grids (HEX vs. HEX), square grids against square grids (SQU vs. SQU), and irregular polygons against irregular polygons (ADMIN vs. ADMIN)—so that geometric structure remained constant within each comparison pair (cf. fig. 3a-c). These stimulus maps were integrated into corresponding comparative layouts using two Esri ArcGIS Online Instant Apps templates (cf. Popelka et al., 2022): Basic (for the Slider / SL layout) and Compare (for the Side-by-Side / SBS layout). To precisely record user performance, a custom browser plugin was developed to log response latencies and error counts directly into a structured text log.

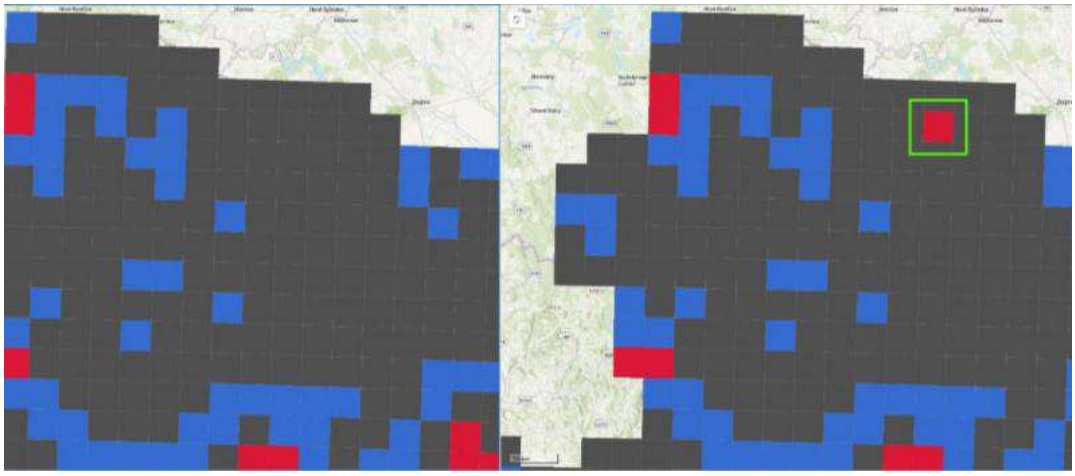


Fig. 3a. Example of a low complexity (C_L) task stimulus embedded in a square grid (SQU) juxtaposition layout. The target anomaly (highlighted with a green box for the purpose of this illustration) is positioned centrally within a homogeneous data cluster.

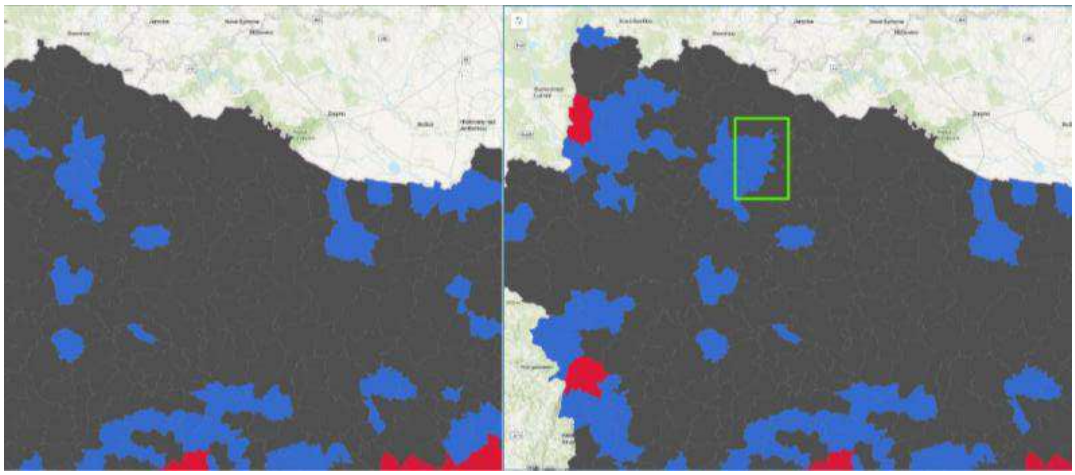


Fig. 3b. Example of a medium complexity (C_M) task stimulus embedded in irregular administrative polygons (ADMIN). The target anomaly (highlighted with a green box for the purpose of this illustration)is located along a regional cluster boundary.

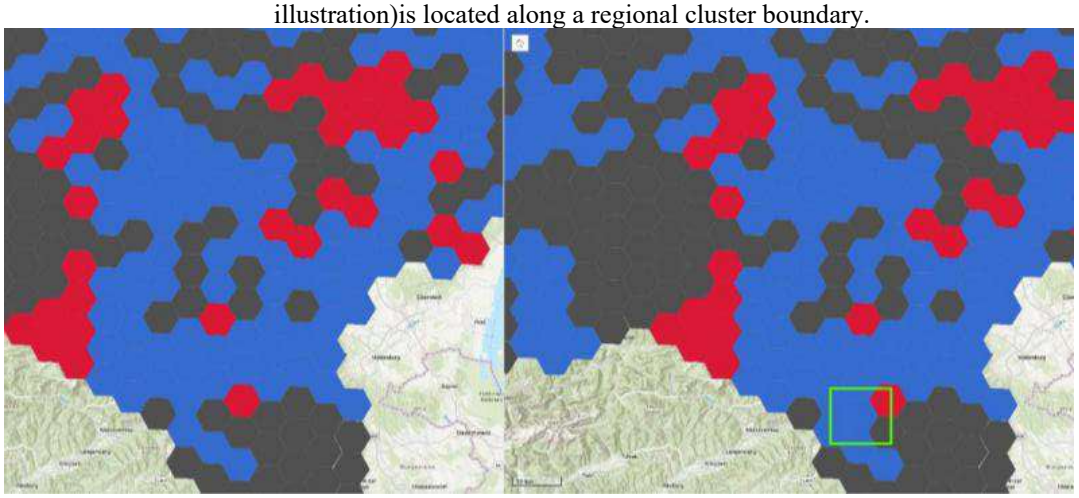


Fig. 3c. Example of a high complexity (C_H) task stimulus embedded in a hexagonal grid (HEX). The target anomaly (highlighted with a green box for the purpose of this illustration) is placed within an area of high visual noise with no clear surrounding spatial pattern.

3.3 Procedure

The study took place in a computer lab at BHT, uniformly equipped with 24-inch Full HD (1920 x 1080 px) monitors. Operating instructions and tutorial tasks were provided at an initial training site.

Participants were told that every pair of maps is identical except for the color of one polygon, and their task is to find and click on the anomaly. Correct and incorrect clicks triggered immediate visual feedback text on the screen. Upon selecting the correct target polygon, the browser plugin automatically logged latency and errors. Participants advanced through the 9 core task pairs sequentially after demonstrating familiarity with map navigation and interaction tools.

4. Results

4.1 Layout analysis: precision and error rates

To evaluate user precision, Welch t-tests were conducted on error counts across comparative layouts due to unequal group variances. Table 1 summarizes metrics across all geometry and complexity combinations. Under low complexity (C_L), juxtaposition (SBS) demonstrated higher visual precision for hexagonal (p = .008) and square (p = .001) grids. However, as spatial complexity increased to medium (C_M), the slider-based layout (SL) significantly reduced error rates in irregular administrative polygons (p = .010).

geometry & complexity	*SBS mean error*	*SL mean error*	*test statistic (p-value)*	*superior layout*
hexagon - low (HEX-C_L)	**1.00**	**2.57**	**p = .008***	**SBS**
hexagon - medium (HEX-C_M)	2.47	2.43	p = .960	—
hexagon - high (HEX-C_H)	4.65	2.33	p = .085	—
square - low (SQU-C_L)	**0.79**	**1.89**	**p = .001***	**SBS**
square - medium (SQU-C_M)	3.00	3.79	p = .480	—
square - high (SQU-C_H)	5.93	4.21	p = .397	—
polygon - low (ADMIN-C_L)	1.94	2.13	p = .763	—
polygon - medium (ADMIN-C_M)	**12.88**	**2.05**	**p = .010***	**SL**
polygon - high (ADMIN- C_H)	19.57	8.79	p = .124	—

Table 1. Layout precision comparison (error rates). Statistically significant values (p < .05) are highlighted in bold with asterisks.

A one-way ANOVA evaluated the main effect of spatial discretization geometry on error counts within each layout (table 2). Irregular administrative polygons systematically increased user error counts compared to regular grid cells across medium and high complexity thresholds in both layouts.

interface layout	*complexity level*	*F-statistic*	*degrees of freedom (df)*	*test statistic (p-value)*
SBS	low (C_L)	F = 1.431	df = 2, 48	p = .249
SBS	**medium (C_M)**	**F = 6.208**	**df = 2, 50**	**p = .004***
SBS	**high (C_H)**	**F = 6.086**	**df = 2, 47**	**p = .004***
SL	low (C_L)	F = 1.000	df = 2, 53	p = .375
SL	**medium (C_M)**	**F = 4.023**	**df = 2, 52**	**p = .024***
SL	**high (C_H)**	**F = 5.634**	**df = 2, 48**	**p = .006***

Table 2. Main effect of discretization geometries on errors (one-way ANOVA). Statistically significant values ($p < .05$) are highlighted in bold.

4.2 Layout analysis: visual efficiency and response times

Task completion time distributions showed a characteristic right-skewness (Whelan, 2008), prompting Welch t-tests to assess visual efficiency differences (table 3). Under low complexity (C_L), response times were comparable between layouts for regular grids, but SL was significantly faster for irregular polygons ($p = .010$). Across medium (C_M) and high (C_H) complexity levels, SL demonstrated substantial efficiency gains, e.g. reducing completion times by up to fivefold in square grids (tab. 3: row 6).

geometry & complexity	*SBS mean time*	*SL mean time*	*test statistic (p-value)*	*superior layout*
hexagon - low (HEX-C_L)	12.60 s	12.00 s	p = .854	—
hexagon - medium (HEX-C_M)	**39.77 s**	**14.92 s**	**p = .005***	**SL**
hexagon - high (HEX-C_H)	**87.90 s**	**20.34 s**	**p = .001***	**SL**
square - low (SQU-C_L)	11.77 s	9.26 s	p = .295	—
square - medium (SQU-C_M)	29.85 s	31.10 s	p = .883	—
square - high (SQU-C_H)	**153.25 s**	**28.67 s**	**p = .003***	**SL**
polygon - low (ADMIN-C_L)	**36.55 s**	**14.80 s**	**p = .010***	**SL**
polygon - medium (ADMIN-C_M)	**88.77 s**	**35.36 s**	**p = .004***	**SL**
polygon - high (ADMIN-C_H)	**304.87 s**	**84.55 s**	**p = .000***	**SL**

Table 3. Layout visual efficiency comparison (response times in seconds). Statistically significant values ($p < .05$) are highlighted in bold.

A one-way ANOVA confirmed that spatial discretization geometry significantly affected response latency across complexity levels (table 4). Regular hexagonal grids yielded the fastest response times across all conditions, whereas irregular administrative polygons consistently induced performance bottlenecks.

interface layout	*complexity level*	*F-statistic*	*degrees of freedom (df)*	*test statistic (p-value)*
SBS	**low (C_L)**	**F = 5.360**	**df = 2, 48**	**p = .008***
SBS	**medium (C_M)**	**F = 9.675**	**df = 2, 49**	**p = .000***
SBS	**high (C_H)**	**F = 13.067**	**df = 2, 47**	**p = .000***
SL	low (C_L)	F = 1.951	df = 2, 51	p = .153

SL	**medium (C_M)**	**F = 3.758**	**df = 2, 53**	**p = .030***
SL	**high (C_H)**	**F = 10.627**	**df = 2, 51**	**p = .000***

Table 4. Main effect of discretization geometries on response times (one-way ANOVA). Statistically significant values ($p < .05$) are highlighted in bold.

5. Discussion

5.1 Synthesis of results

Overall, our findings support the hypothesis that animated transition (SL) facilitates higher visual efficiency over static juxtaposition (SBS) in choropleth map comparison, particularly as structural complexity is high. Across medium and high complexity profiles, response times were substantially lower in slider-based transition (SL), aligning with findings by Lobo et al. (2015) and Svicorovic et al. (2021). The slider leverages motion sensitivity (Rensink, 2002) and, thus, enables faster target localization. Performance was, however, not constant across task complexity: in hexagonal and square grids, juxtaposition (SBS) showed significantly fewer incorrect clicks than slider-based transition (SL). This underlines the concern of Popelka et al. (2022), that swipe tools excel at change localization but can create—albeit interactively beneficial—interaction noise and cognitive overheads within simple layouts. A static side-by-side viewport is a helpful and stable baseline for precise verification if the visual clutter is low (L'Yi et al., 2021).

Consequently, our findings mirror and contextualize existing research in all its apparent heterogeneity: If previous experiments comparing slider and side-by-side layouts produced mixed and sometimes contradictory outcomes, our findings clarify that these divergent empirical results are not mutually exclusive, but rather represent distinct points along a continuum of task complexity and geometric structure. Instead of reducing interface evaluation to a “better vs. worse” dichotomy, our findings study suggests that layout efficacy is highly contextual. By establishing these trade-offs, this study contributes a more nuanced framework for understanding when and why certain map comparison techniques work.

A major contribution of the results obtained lies in demonstrating that spatial discretization geometry is a significant moderating variable of visual performance. Hexagonal grids yielded consistently the fastest response times and highest precision, which could be attributed to “preserving the mental map of a user” (Forsch et al., 2024): hexagonal tessellations maintain equal neighborhood adjacencies and centroid distances, enabling users to preserve cognitive schematization during transitions. In contrast, irregular administrative boundaries rapidly constitute a complexity ceiling and decrease visual performance through boundary topology noise and area-size bias (Schiewe, 2019).

5.2 Future research

While map comparison has been a core activity throughout cartographic history, the exponential increase of spatiotemporal geodata generated by continuous remote sensing, sensor networks, and high-resolution spatial modeling puts unprecedented pressure on comparative visualization workflows (Kraak & Ormeling, 2020). Future research should expand upon these findings in several directions:

- Multi-feature anomalies: Evaluating scenarios where multiple dispersed or clustered polygons systematically undergo simultaneous value shifts to ascertain if slider-based transition (SL) maintains its efficiency under distributed visual attention.
- Color, contrast, and class density: Investigating classification thresholds (e.g., 3-class vs. 7-class choropleth maps) to identify where visual overload diminishes the slider's speed advantage.
- Spatial heterogeneity metrics: Establishing quantitative shape metrics (e.g., compactness, perimeter-to-area ratios) to identify exact heterogeneity thresholds where regular tessellations offer statistically outperform real-world administrative units.

6. Conclusion

This paper's principal contribution is an empirical evaluation of comparative interaction idioms (SL vs. SBS) and spatial discretization geometries (HEX, SQU, ADMIN) in terms of their effects on visual efficiency and accuracy when comparing choropleth maps. Our user study showed that animated transition (SL) significantly enhances visual efficiency, although juxtaposition (SBS) provides more accuracy in less complex tasks. Further, spatial discretization geometry mediates visual performance: hexagonal grids maximize visual search efficiency.

A comprehensive research agenda from cartography, spatial cognition, and human-computer interaction is needed to solidify these comparison techniques, classification schemes, and geometries under real-world data loads. Still, this study establishes an empirical benchmark for comparative layout trade-offs in user-centric optimization of contemporary geovisualization interfaces.

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Conflict of interest statement: On behalf of all authors, the corresponding author states that there is no conflict of interest.