Blossom Glyph: Design and Evaluation of a Glyph for Paired Multivariate Data

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ABSTRACT
In many analytical domains, evaluating complex entities requires interpreting paired multivariate data, such as imports versus exports, rather than independent attributes. While traditional glyphs prioritize technical encoding efficiency and quantitative readability, they frequently lack the aesthetic form and structural coherence needed to convey the relational balance of paired values. Inspired by the nature scenes of flowers and stars, we design *Blossom Glyph*, a compact representation that integrates paired attribute sets into a single spatially aligned mark, supporting direct attribute-level comparison and holistic perceptions of asymmetry. We evaluated Blossom Glyph in a crowdsourced study against a diverging bar chart and a grouped radial chart. To demonstrate its flexibility across various layouts, we present case studies in geospatial forestry trade, music influence networks, and basketball roster movement. Results show that Blossom Glyph offers an effective balance between within-glyph readability and across-glyph holistic comparison, making it well-suited for paired multivariate data. All study results and code are available at `https://github.com/THENABINKHANAL/BlossomGlyph.git`.

KEYWORDS
Glyph design, multivariate data, relational visualization, radial visualization.

1. Introduction

Glyph-based designs are a fundamental strategy for compact multivariate comparison, enabling analysts to inspect many complex entities within a shared spatial or structural context (Borgo et al., 2013; Ward, 2008). Yet most multivariate glyphs are designed to summarize a single set of attributes for each entity (Borgo et al., 2013; Ropinski, Oeltze, & Preim, 2011; Ward, 2008). In many analytical settings, however, the task is to compare paired values for the same entity, such as imports versus exports, incoming versus outgoing influence, or gains versus losses. Analysts must compare corresponding dimensions while also judging the pair as a whole, in terms of balance, asymmetry, or overall profile structure, making the task one of both quantitative comparison and visual comparison of complex objects (Gleicher et al., 2011; Koc, McGough, & Johansson Fernstad, 2022). This challenge becomes more difficult when many paired multivariate profiles must be compared across small multiples (Gleicher et al., 2011;

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Lekschas et al., 2021). Moreover, many established glyph designs emphasize technical encoding efficiency and quantitative readability, while giving less attention to aesthetic form, visual appeal, and the expressive potential of glyphs as holistic visual objects.

In this paper, we introduce **Blossom Glyph**, a glyph representation designed for paired multivariate data. Inspired by the structure and visual metaphor of blooming flowers, Blossom Glyph uses a petal-like form to integrate paired attribute sets into a single spatially aligned mark. It encodes matched dimensions at fixed angular positions and uses an inward-outward structure to couple two related profiles within a single mark. The design supports both direct attribute-level comparison and higher-level judgments of balance, dominance, similarity. Informed by prior work on multivariate glyph design, balanced structures, and comparison-oriented glyphs, it is designed to address cases in which multivariate profiles must be read together rather than independently (Borgo et al., 2013; Chung et al., 2015; Koc et al., 2022; Ward, 2008).

To evaluate Blossom Glyph against established baselines, we compare it with a diverging bar chart and a grouped radial chart in a crowdsourced study using country-level forestry trade data. These baselines provide useful points of comparison because they support different strengths in relationally paired multivariate data reading, including aligned magnitude comparison and compact profile-based interpretation (Cleveland & McGill, 1984). The study includes nine task types derived from established visualization task taxonomies, spanning local lookup, paired comparison, profile matching, outlier detection, regional summarization, and temporal trend interpretation.(Amar, Eagan, & Stasko, 2005; Brehmer & Munzner, 2013; Lee, Plaisant, Parr, Fekete, & Henry, 2006). The evaluation systematically compares different visual representations, examining both overall performance and the specific types of analytical reasoning each best supports. We investigate the following research questions:

RQ1 (Effectiveness): Does Blossom Glyph achieve comparable or higher accuracy than baseline visualizations across tasks on paired multivariate data?

RQ2 (Efficiency): Does Blossom Glyph enable comparable or faster response times than baseline visualizations on the same tasks?

RQ3 (Task-Specific Strengths): Is Blossom Glyph well suited to specific tasks such as similarity matching, outlier detection, or profile summarization?

RQ4 (Aesthetics and Preference): Do participants find Blossom Glyph more aesthetically pleasing, learnable, or preferable to use than baseline visualizations?

This paper makes three main contributions. First, it introduces Blossom Glyph, a compact glyph for paired multivariate data that supports both within-glyph and across-glyph reading. Second, it presents a comparative user study that evaluates Blossom Glyph against Cartesian and radial baselines across a mixed task set grounded in established task taxonomies. Third, it situates the design within the broader context through case studies in geospatial trade, music influence, and basketball roster movement, demonstrating its applicability in various use cases.

2. Related Work

We situate our work on paired values from three perspectives: characterizing and visualizing paired data, glyph design and motif simplification, and the perceptual and empirical foundations of glyph-based comparison.

2.1. Relational Visualization of Paired Data

Many analytical datasets are organized as paired values, including academic influence as incoming and outgoing citation flows (Shin et al., 2019), international trade as paired imports and exports (Setayesh, Sourati Hassan Zadeh, & Bahrak, 2022), and paired directional states in network and flow data more generally (Ma et al., 2017). In this paper, we refer to ***paired values*** as two linked attribute sets per entity whose dimensions correspond one-to-one, such as imports and exports of the same product category, or incoming and outgoing influence of the same category. Unlike conventional multivariate data, where an entity is summarized by a single attribute set, paired data requires the two sets to be interpreted together. Viewers must compare matched values, judge balance or asymmetry, and read the pair as a unified profile (Gleicher, 2018; Gleicher et al., 2011). When many such profiles are placed side by side, the analytical goal extends beyond reading any single entity to identifying relations across entities such as recurring shapes, balance trends, or structural outliers (Lekschas et al., 2021). We refer to representations that support reading both paired values within each mark and comparison across many marks, as ***relational visualization of paired data***. Prior approaches illustrate the difficulty of supporting both readings at once. Standard flow visualizations preserve paired direction and magnitude in principle, but often overwhelm viewers with edge crossings and visual clutter (Vrotsou, Fuchs, Andrienko, & Andrienko, 2017).One response has been the use of symmetric or mirrored glyphs that place paired states into direct correspondence at a single location, rather than splitting them across separate views (Ma et al., 2017). This reflects a recurring strategy for visualizing paired data: condensing complex network structure into a localized summary, an idea that also underlies egocentric visualization (Shi et al., 2015).

Egocentric visualization organizes data around a focal entity to reveal its specific interactions and roles within a broader system (Freeman, 1982; Perry, Pescosolido, & Borgatti, 2018). This "focal-point" approach is particularly effective for managing paired multivariate data; for example, *Influence Flowers* uses a radial, floral metaphor within a node-link diagram to simultaneously visualize a researcher's incoming and outgoing academic influence (Shin et al., 2019). While powerful, these techniques are typically embedded in specialized network interfaces where the user examines one focal entity at a time. Blossom Glyph leverages this egocentric logic condensing incoming and outgoing relationships into a localized summary, but reformulates it as a compact multivariate glyph. Rather than requiring a dedicated network view, it is designed as an embeddable mark that can be used in high-density layouts such as geospatial maps or timelines, supporting simultaneous comparison across many entities.

2.2. Multivariate Glyphs and Motif Simplification

Glyphs map several data attributes onto the components of a compact graphical mark, making them well suited to comparing many multivariate entities within a shared spatial context (Borgo et al., 2013; Fuchs, Isenberg, Bezerianos, & Keim, 2017; Ward, 2008; Zhao et al., 2020). Their effectiveness, however, is sensitive to choices of visual channel, dimension order, and layout, particularly in the dense settings where viewers must compare many marks at once to identify extrema, compare attributes, detect outliers, match similar profiles, or summarize overall patterns. (Borgo et al., 2013; Fuchs et al., 2017; Ward, 2008). Blossom Glyph draws on two strands of this literature. The first treats glyphs as *motif simplifications*, where compact marks replace recurring structural patterns with an interpretable summary. Dunne and Shneiderman's fan, connector, and clique glyphs show that repeated graph motifs can be collapsed into single marks that reduce clutter while preserving essential relational structure (Dunne & Shneiderman, 2013). Blossom Glyph applies this logic to paired data, compressing repeated in/out relationships around an entity into a single radial form rather than drawing many separate directional links. The second strand designs glyphs specifically to support structural judgments such as sorting, balance, and asymmetry. Glyph Sorting argues that multivariate glyphs should be built around ordered comparison, visual search, and learnable structure through carefully chosen channels and separable encodings (Chung et al., 2015). Subsequent designs have refined this in different directions. For instance, *Leaf Glyph*, is oriented toward ***across-glyph reading***, using expressive shape variation and aggregation to keep many repeated marks visually discriminable for pattern and outlier detection (Fuchs, Jäckle, Weiler, & Schreck, 2015). *PeaGlyph* is an example more oriented toward ***within-glyph reading***, using symmetric structure to make balance directly perceivable in a single mark (Koc et al., 2022). Both, however, address conventional multivariate data, where balance and pattern are computed within a single attribute set. Blossom Glyph extends this line of work to paired data, preserving pairwise correspondence within each mark while staying discriminable across many marks at once.

2.3. Profile Comparison and Glyph Evaluation

To support comparison across many entities at once, Gleicher et al. identify three core strategies, juxtaposition, superposition, and explicit encoding, which can be combined to form hybrid designs (Gleicher et al., 2011; Lekschas et al., 2021). Blossom Glyph draws primarily on juxtaposition through dense multiples layout and on explicit encoding within each mark, where the bilateral inward-outward structure makes the paired relationship itself visible. Perceptual performance also depends on how data attributes are mapped to visual channels. Cleveland and McGill demonstrated that aligned position and length support more accurate quantitative judgments than angle and area (Cleveland & McGill, 1984), so compact radial glyphs often trade some quantitative precision for the holistic form they afford. Blossom Glyph is designed around this trade-off, preserving enough local structure for attribute-level reading while producing a recognizable silhouette that remains consistent across many marks for ease of comparison. Empirical work on glyphs suggests this tradeoff is task-dependent rather than absolute. Chau's evaluation of a flower-based glyph for web search found that glyph-based and combined displays can better support complex comparison tasks than conventional alternatives (Chau, 2011). Fuchs et al. showed that performance in multiple glyph settings varies substantially with the specific design chosen (Fuchs, Fischer, Mansmann, Bertini, & Isenberg, 2013), and *PeaGlyph* demonstrated that glyph structure can influence judgments of balance and imbalance (Koc et al., 2022). At a methodological level, visualization evaluation research argues that empirical assessments should be matched to the analytical goals a visualization is meant to support (Carpendale, 2008; Lam, Bertini, Isenberg, Plaisant, & Carpendale, 2012). Our study aims to address the gap in evidence on how a compact glyph designed for paired multivariate data performs against familiar baselines across a mixed task set.

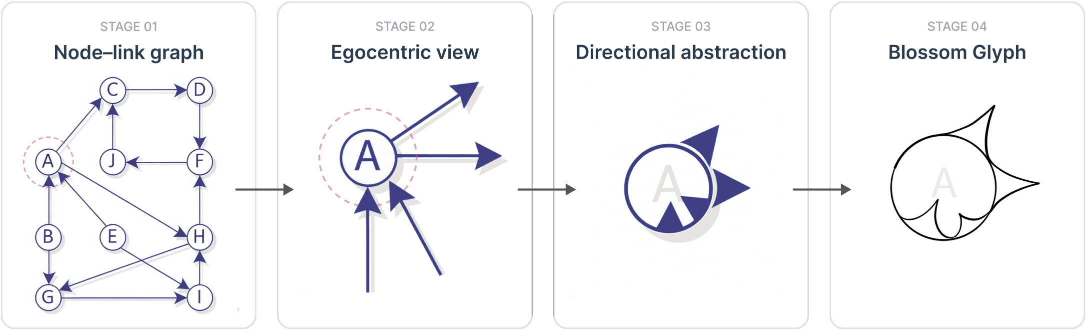


Figure 1.: Conceptual development of Blossom Glyph.

3. Design

We present the design rationale for Blossom Glyph, starting with its initial inspiration, then distilled design principles, finalized visual encodings, and code implementation.

3.1. Concept and Origins

Blossom Glyph originated from an effort to condense and synthesize the node-link graph itself. Traditional network visualizations often depict a node surrounded by numerous directed edges, some entering and some exiting, resulting in dense and overwhelming visual patterns. During early experimentation, we examined these directional connections and sought to represent their essence within the node itself. Inward edges were abstracted into inward-facing spokes, while outward edges were represented as outward-facing spokes. This transformation internalized directional connectivity into the node's geometry, as seen in Figure 1. When aggregated and rendered symmetrically, these lobes produced an organic, flower-like contour that inspired the name Blossom Glyph. Therefore, Blossom Glyph functions as a self-contained summary, collapsing numerous directional edges into a compact, efficient form that reduces the visual scanning and interpretive effort.

3.2. Design Principles

The design of Blossom Glyph builds on established research in multivariate glyph construction and perceptual design. Foundational principles of sortable glyphs (Chung et al., 2015) and balanced data representation (Koc et al., 2022) provide theoretical grounding for the encoding choices and overall visual structure. The following principles summarize the main design considerations that guided Blossom Glyph, aligning perceptually effective designs with the visual literacy needed to interpret them:

- **Readability:** The glyph's clear inward-outward organization, consistent angular spacing, and distinct segment boundaries support interpretation of relational patterns, enabling rapid perception of the encoded structure.
- **Symmetry and Equilibrium:** Bilateral inward-outward mapping visually expresses balance or imbalance between paired values, making profile symmetry an immediate perceptual cue.
- **Gestalt Coherence:** The glyph leverages Gestalt principles such as similarity, proximity, and closure to enable users to perceive distributed attributes as a unified

pattern rather than as discrete components.

- **Aesthetics:** The organic form, smooth contour, and minimalist configuration contribute to visual appeal, supporting engagement and sustained attention in visualization settings.
- **Directional Affordance:** The inward-outward structure provides a straightforward cue for paired directionality: outward-dominant petals indicate outgoing values, while inward-facing segments indicate incoming values. This supports immediate judgments of dominance and rapid scanning for recurring silhouettes or structural outliers in spatial and temporal views.
- **Searchability/Trend Recognition:** The consistent radial geometry allows viewers to quickly locate specific attributes for comparison even within dense visual contexts.
- **Learnability and Memorability:** The recognizable radial structure and repeating positions promote learning and long-term memory. Repeated exposure strengthens the association between contour shapes and relational patterns.
- **Channel Capacity:** Multiple data properties are encoded within a small visual motif without overloading perceptual channels, ensuring compact yet expressive communication.
- **Contextual Stability:** The design sustains recognizability across scales (e.g., number of glyphs) and contexts, ensuring robustness in dense network visualizations while maintaining coherence between local and global structures.
- **Temporal Adaptability:** The glyph's structure can accommodate morphing over time to express change without re-encoding.
- **Typedness:** Each data attribute is mapped to an appropriate visual channel aligned with its semantic data type: quantitative attributes to length and size, categorical attributes to angular position and color.

3.3. Visual Encoding

Structure. Each glyph is constructed in polar coordinates and consists of multiple bilateral "petals" arranged around a central point. The glyph's circular zero baseline represents a state of neutrality between inward and outward effects. Inward and outward ranges are relative, scaling with the glyph's radius and magnitude of data. Blossom Glyph encodes each property of the paired profile through a dedicated visual channel, as detailed in Figure 2.

Angle. To avoid giving any single dimension privileged alignment with the vertical axis, the glyph is designed with a slight rotational offset (e.g., 10° clockwise/counterclockwise) rather than placing a petal exactly vertical at the "12 o'clock" position. This aims to reduce unintended cardinal-axis and vertical-symmetry salience, since vertical and horizontal orientations are perceptually privileged over diagonal ones, known as the oblique effect (Appelle, 1972; Wenderoth, 1994).

Parametric Variations. The design's implementation supports a parametric glyph in which the number of petals, inward and outward magnitudes, baseline radius, and petal curvature can be adjusted interactively. This allows Blossom Glyph to be explored as a family of related forms rather than a single fixed geometry. Radius is particularly important because inward values are encoded inside the baseline circle and are constrained by the available interior space. Changing the radius therefore changes the glyph's representational capacity and can reduce compression of large inward magnitudes.

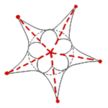
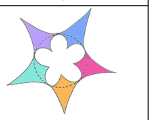
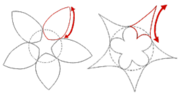
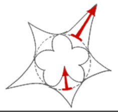
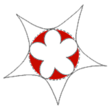
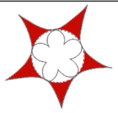
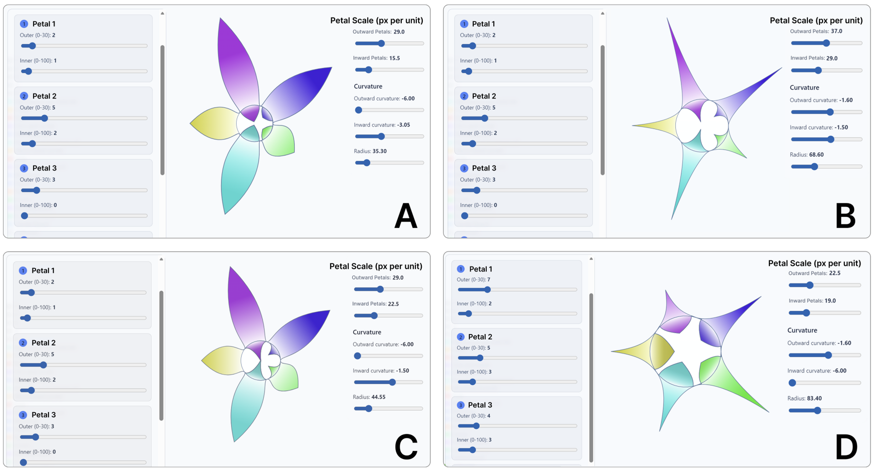
Visual Channel	Encoded Properties	Rationale	Visual Example
Angle	Category / dimension / attribute	Maintains a fixed position for each category, supporting across-glyph comparison.	
Color	Category identity	Reinforces category differentiation and supports quick identification of corresponding dimensions.	
Curvature	Petal character / reading strategy	Shapes whether petals read as broader convex or sharper concave forms, affecting closure, directional polarity, & the balance between holistic profile reading & local discrimination.	
Length	Magnitude	Provides a strong cue for quantitative comparison, supporting judgments of relative strength within-glyph & across-glyph.	
Inward directionality	Incoming paired value	Represents one paired attribute set through a consistent inward spatial mapping.	
Outward directionality	Outgoing paired value	Represents the corresponding paired attribute set through a consistent outward spatial mapping.	
Glyph radius	Overall size	Provides a holistic cue to the overall size or area of the entity.	

Figure 2.: Mapping between the visual channels and encoded properties.



A

Petal 1
Outer (0-30): 2
Inner (0-100): 1
Petal 2
Outer (0-30): 5
Inner (0-100): 2
Petal 3
Outer (0-30): 3
Inner (0-100): 0

Petal Scale (px per unit)
Outward Petals: 29.0
Inward Petals: 15.5
Curvature
Outward curvature: -6.00
Inward curvature: -3.05
Radius: 35.30

B

Petal 1
Outer (0-30): 2
Inner (0-100): 1
Petal 2
Outer (0-30): 5
Inner (0-100): 2
Petal 3
Outer (0-30): 3
Inner (0-100): 0

Petal Scale (px per unit)
Outward Petals: 37.0
Inward Petals: 29.0
Curvature
Outward curvature: -1.60
Inward curvature: -1.50
Radius: 68.60

C

Petal 1
Outer (0-30): 2
Inner (0-100): 1
Petal 2
Outer (0-30): 5
Inner (0-100): 2
Petal 3
Outer (0-30): 3
Inner (0-100): 0

Petal Scale (px per unit)
Outward Petals: 29.0
Inward Petals: 22.5
Curvature
Outward curvature: -6.00
Inward curvature: -1.50
Radius: 44.55

D

Petal 1
Outer (0-30): 7
Inner (0-100): 2
Petal 2
Outer (0-30): 5
Inner (0-100): 3
Petal 3
Outer (0-30): 4
Inner (0-100): 3

Petal Scale (px per unit)
Outward Petals: 22.5
Inward Petals: 19.0
Curvature
Outward curvature: -1.60
Inward curvature: -6.00
Radius: 83.40

Figure 3.: Parametric variations of Blossom Glyph created by adjusting curvature, magnitude, and radius. (A) shows a fuller configuration with **convex** petals, while (B) shows a sharper configuration with **concave** petals. (C) combines convex outer petals with concave inner petals, whereas (D) reverses the in and out relationship. Designs (C) and (D) are less suitable as general purpose glyphs because their mixture of convex and concave petals may increase interpretive complexity.

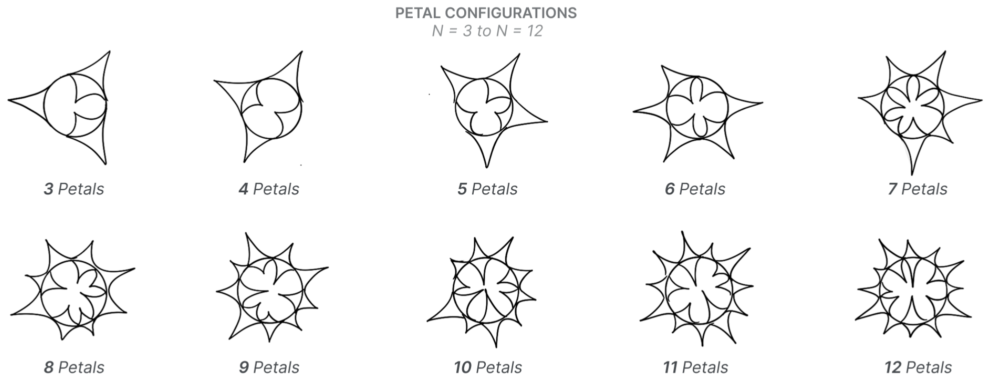


Figure 4.: Blossom Glyph configurations ranging from 3 to 12 petals. Empirical limits on perceptual grouping suggest that configurations with up to seven petals remain most distinct and legible.

Curvature. Parametric variations also show how geometric form shapes the reading strategy. Broader, convex petals (Figure 3A) create a fuller, more continuous form, whereas more pointed, concave petals (Figure 3B) sharpen directional polarity and the separation between adjacent dimensions. Research on perceptual organization indicates that contour coherence, closure, and symmetry determine whether a display is read as a unified form or as separable parts (Wagemans et al., 2012). Visualization research shows that global structural patterns are perceived quickly while local comparisons require more focused attention (Franconeri, Padilla, Shah, Zacks, & Hullman, 2021). Curvature therefore mediates a tradeoff between holistic profile reading and local discrimination. The convex form strengthens closure and supports reading the glyph as a coherent whole, which can aid rapid judgments of overall balance or profile type. However, it also increases each petal's apparent visual weight and encourages area-based interpretation, a weaker quantitative cue than position or length (Cleveland & McGill, 1984). The concave form, in contrast, makes directional polarity more explicit, shifts attention toward extension and direction, and preserves a clearer interior structure by reducing central crowding among inward petals.

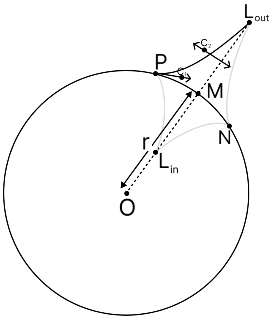
Figure 3C and D show two hybrid settings in which inward and outward curvature are tuned separately. We find these to be weaker encodings because different parts of the glyph begin to imply different reading modes. The convex region can encourage enclosure and area-based reading, whereas the concave region emphasizes extension, direction, and local separation. When these strategies are combined within a single glyph, the visual logic becomes less uniform and the perceptual basis of comparison becomes less stable.

Number of Petals. Another perceptual consideration concerns how many petals can be read clearly within a single glyph while still allowing comparison across many glyphs in a display. In this paper, we discuss and evaluate the glyph primarily in a five-petal configuration, which aligns with the number of dimensions used in our study. However, the design can support more petals, as illustrated in Figure 4. As an upper benchmark, Munzner notes that radial category-based encodings are generally limited to around a dozen categories (Munzner, 2014). Miller's Law suggests that viewers are most effective at processing around seven distinct elements (Miller, 1956). More recent monitor-based work similarly shows that human attention can reliably track about six objects, but that this capacity drops as task demands increase (Bettencourt & Somers, 2009). In visualization settings, viewers must compare many glyphs rather than one mark in isolation, we therefore use five petals to preserve legibility while remaining comfortably below these broader perceptual limits.

Glyph Size. One limitation concerns the asymmetric spatial capacity of the glyph. As the inward values are bounded by the baseline circle while outward values extend away from it, the encoding is most naturally suited to paired data in which inward magnitudes are smaller than outward magnitudes. When inward and outward ranges are comparable to each other, one option is to fix the radius globally using the maximum inward magnitude observed across the dataset so that all glyphs share a common interior scale. When inward magnitudes vary more substantially or exceed outward magnitudes, variable, data-dependent radii can be used to increase interior capacity. However, this flexibility introduces an additional visual channel, because overall glyph size itself begins to communicate magnitude. Larger glyph areas often draw greater visual attention, which is useful when overall magnitude is analytically meaningful. However, if the data range varies substantially, global radius scaling may allow a few large values to dominate the display, whereas local radius scaling can balance glyph size and better reveal within-glyph variation. Thus, the choice between global and local maximum depends on the application scenario: global scaling emphasizes cross-glyph magnitude differences, while local scaling supports visually balanced comparisons within each glyph.

In summary, Blossom Glyph is better understood not as a single fixed contour, but as a family of related glyph designs that preserve the same inward-outward relationship while allowing radius, curvature, and number of petals to adapt to different data dimensions, data ranges, display constraints, and analytical priorities.

3.4. Blossom Glyph Implementation



Our implementation renders Blossom Glyphs as browser-based SVG elements using JavaScript libraries, with React supporting user interface organization and D3.js supporting data transformation, geometric calculations, and SVG path generation. We present the geometric construction of one petal in Blossom Glyph. Each glyph encodes a paired multivariate profile with D dimensions, where each dimension contributes one outward and one inward magnitude. The implementation accepts inward and outward values as input, supports optional data transformation such as local maximum or global maximum normalization, and maps the transformed values to screen-space radial displacements using separate scale parameters:

$$\ell_i^{\text{out}} = s_{\text{out}}\, x_i^{\text{out}}, \qquad \ell_i^{\text{in}} = -\, s_{\text{in}}\, x_i^{\text{in}}.$$

Positive displacements extend beyond the baseline circle, while negative displacements pull petals inward toward the center. All geometry is constructed in polar coordinates around a common center O with baseline radius r. The D dimensions are placed in fixed angular order. The sector width is

$$\theta_w = \min\left(\frac{2\pi}{D}, \frac{\pi}{2}\right),$$

with any unused angular span distributed symmetrically around the circle. For dimension i, the two boundary points on the baseline circle are

$$P_i = \big(r\cos\theta_{i,1},\, r\sin\theta_{i,1}\big), \qquad N_i = \big(r\cos\theta_{i,2},\, r\sin\theta_{i,2}\big).$$

The midpoint between P_i and N_i is projected back to the circle to define M_i, the central radial axis point of the petal. Let u_i be the unit vector from O through M_i. The outward and inward endpoints are placed along this axis as

$$L_i^{\mathrm{out}} = M_i + \ell_i^{\mathrm{out}} u_i, \qquad L_i^{\mathrm{in}} = M_i + \ell_i^{\mathrm{in}} u_i.$$

Each petal is then drawn with two cubic Bézier curves, from P_i to L_i and from L_i to N_i, where L_i is either L_i^{out} or L_i^{in}. Curvature is controlled by offsetting an intermediate radial point B_i laterally along the tangent direction of the circle. If f denotes the curvature parameter, the lateral offset magnitude is

$$k = 12(f + 1).$$

The corresponding midpoint Bézier control points are $C_{i,1} = B_i + k\,t_i$ and $C_{i,2} = B_i - k\,t_i$, where t_i is the local tangent direction. Smaller f produces narrower, sharper petals, whereas larger f produces broader, rounder petals. Additional tangent-aligned control handles at P_i and N_i ensure a smooth attachment to the baseline circle.

After all petals are generated, the implementation traverses them in angular order and inserts circular arc segments wherever adjacent sectors do not meet, yielding a merged outer border. The baseline circle is also drawn separately, and the component can optionally render an outer reference circle to indicate the maximum outward extent under the current scaling. Therefore, the final glyph is assembled from SVG path definitions for the petals, merged border, baseline circle, and optional reference circle. Optional labels, legends, center text, and pan-and-zoom interaction are supported, but these are auxiliary to the core geometric encoding.

4. Use Cases

We show the usefulness of Blossom Glyph in three scenarios: arranging glyphs on a timeline, overlaying them on a map, and positioning them in a fixed order. Across all three use cases, glyph radius is scaled using a global maximum, so that every glyph shares a common interior and exterior scale and remains directly comparable.

4.1. Music Influence in a Person-Centric Knowledge Graph

Our first case study applies Blossom Glyph to the person-centric music knowledge graph explored through *Melody Way* and further extended in *BlossomNet* for 2025 IEEE VAST Challenges (Qaiser et al., 2025; Zong et al., 2025). Blossom Glyph acts as a compact egocentric representation of an artist's relational influence profile, compressing incoming and outgoing relationships into a single mark that can be embedded within larger network or temporal views (Figure 5). Inward petals represent influence received, outward petals represent influence exerted, and fixed semantic positions preserve correspondence across artists. Fixed angular positions encode specific relationship types, including "Cover Of", "Directly Samples", "Interpolates From", "Lyrical

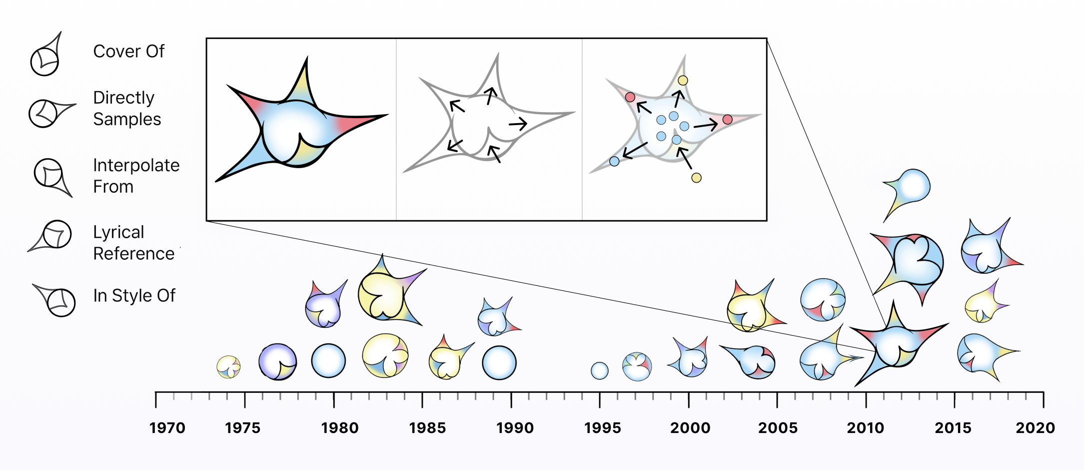


Figure 5.: Blossom Glyphs on a timeline summarize each artist's incoming and outgoing influence, with angle and color encoding influence type and genre.

Reference To", and "In Style Of", allowing analysts to distinguish both the volume and type of influence. Assigning each relationship type to a fixed angular position allows analysts to distinguish not only how much influence surrounds an artist, but also what kind of influence is dominant. Color and gradient further extend this encoding. Hue indicates musical genre (e.g., rock, pop, etc.), while gradient transitions show the genre relationship between the artist and the connected influence, allowing each petal to convey both influence type and cross-genre association. As a result, the visualization communicates the broader structure of an artist's musical lineage, such as whether an artist is primarily shaped by earlier influences, serves as a strong diffuser of style, or occupies a more balanced intermediary role across genres.

The primary strength of Blossom Glyph in this context is transforming dense local graph structures for large scale comparison. Although traditional node-link diagrams emphasize detailed node-to-node connectivity, they can obscure aggregate directional patterns in dense "hairball" structures (Both, Dehmamy, Yu, & Barabási, 2023). Blossom Glyph provides a complementary abstraction by summarizing each artist's multivariate connections into a compact glyph of influence received and influence exerted. This supports rapid scanning for recurring influence patterns or distinguishing originators from followers. Placed along a timeline, the glyphs support temporal reasoning because each entity preserves the same angular positions, bilateral mapping, and global radius. This makes chronologically ordered glyphs directly comparable, allowing viewers to trace whether an artist's influence becomes more outward-dominant, more structurally broad, or more cross-genre over their career.

4.2. Forestry Trade on a Geospatial Map

The second case study applies Blossom Glyph to country-level forestry trade data from the FAOSTAT Forestry Production and Trade database (Food and Agriculture Organization of the United Nations, 2023) that provides annual production and trade statistics for forest products. As shown in Figure 6, each glyph summarizes imports and exports across five wood product categories: "Wood based panels", "Pulp", "Roundwood & sawnwood", "Paper & paperboard", and "Bioenergy". Each category is as-

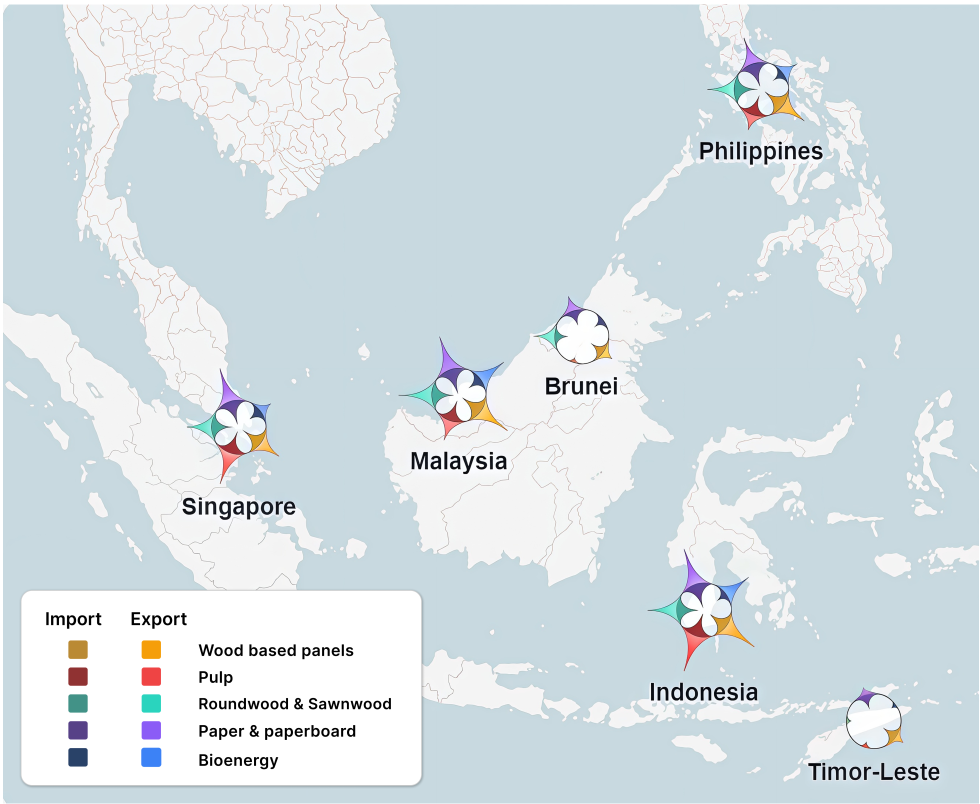


Figure 6.: Country-level Blossom Glyphs on the Southeast Asia map show how forestry trade profiles vary across the region, highlighting contrasts in overall trade volume, directional balance, and category emphasis across neighboring countries.

signed a fixed angular position and color so that profiles remain directly comparable across countries. Inward petals encode imports and outward petals encode exports, allowing viewers to see not only whether a country is more import-heavy or export-heavy overall, but also which product categories drive that pattern. Blossom Glyph makes national trade profiles readable on a map, without separating them from their geographic context. Rather than shifting attention between map locations and auxiliary charts, viewers can interpret import-export balance, category mix, and overall trade structure directly at each country's location. This supports comparison of countries as multivariate trade profiles, revealing whether a profile is balanced or asymmetric, specialized or diversified, and whether it aligns with or departs from broader regional patterns. Blossom Glyph makes it easier to move between local within-glyph inspection and across-glyph regional reasoning, revealing both specific country trade roles and larger geographic patterns.

4.3. NBA Basketball Team Turnover Profiles

Our third case study uses NBA roster movement data derived from the NBA Database on Kaggle (Walsh, n.d.). Each team is summarized annually by positional turnover, representing the number of players joining versus leaving across positions. Each team is shown as a Blossom Glyph, allowing season-to-season comparison across the league. Petals correspond to player positions, while inward and outward directionality distin-

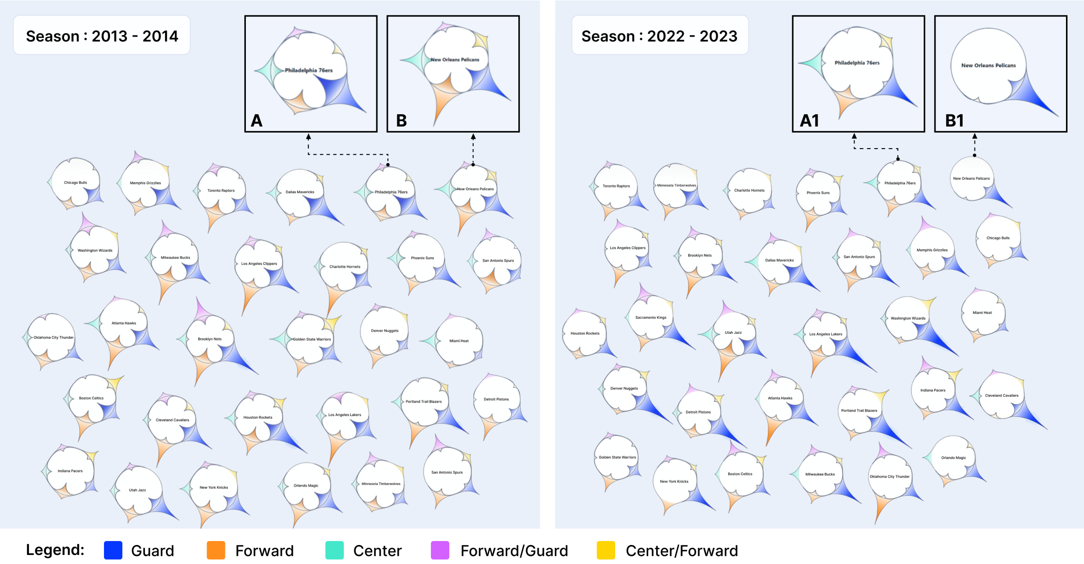


Figure 7.: Blossom Glyphs summarize team-level NBA roster turnover for 2013–14 (left) and 2022–23 (right), with color encoding position groups. Differences in glyph contour captures season-to-season shifts in the magnitude and positional structure of player movement.

guish incoming and outgoing roster movement. This transforms a collection of discrete transactions into a compact organizational profile that can be compared across teams and across time. The key strength of the glyph is that it reveals the structure of roster change, not just the amount of it. Teams making focused adjustments appear as asymmetric shapes with concentrated petals on only a few axes, whereas broad restructurings create more distributed, balanced shapes. When arranged by team and repeated across seasons, Blossom Glyphs support visual comparison of position specific roster movement over time, helping analysts identify stable configurations, localized changes, and broader structural shifts. In other words, Blossom Glyph helps analysts compare team-building strategies as a visual pattern. It exposes whether change is focused or diffused, acquisition-heavy or departure-heavy, and stable or volatile over time in a way that raw transaction lists do not readily convey.

Blossom Glyph also reveals compositional and temporal patterns that extend beyond any single franchise. For example, the 2022-23 season (Figure 7 Right), displays a pronounced guard-oriented asymmetry across most teams, reflecting that both roster movement was concentrated around guard positions and the perimeter focused strategies that characterize the modern NBA. The 2013-14 season (Figure 7 Left), by contrast, produces glyphs with more evenly distributed petals, consistent with a period in which traditional forwards and post players still anchored team construction alongside guards. This contrast demonstrates that Blossom Glyph is sensitive not only to team-level strategies but also to broader shifts in league-wide roster philosophy.

5. User Study

To compare Blossom Glyph against two established multivariate baselines, we conducted a controlled online user study comparing three visual representations: Blossom

Glyph, Diverging Bar Chart, and Grouped Radial Chart. All three encode the same country-level forestry trade dataset (Food and Agriculture Organization of the United Nations, 2023) from the second case study, representing imports and exports across five wood-product categories. Consistent with the case study, all three representations used global maximum scaling, holding overall size constant across trials and conditions so no representation gained an advantage from size alone. Using a within-subjects design, participants completed the same nine tasks under all three visualization conditions, with minor variations in the underlying data values across trials. For each trial, we recorded correctness (RQ1), response time (RQ2), and subjective ratings of clarity, confidence, and aesthetic preference (RQ4).

5.1. *Experimental Factors and Design*

We examine two primary experimental factors: *visual representation* and *analytical task*. The study includes three visual representations and nine analytical tasks. We adopt a within-subjects design, in which each participant completes 27 trials (3 levels of *vis* × 9 *task*). The order of visualization conditions is counterbalanced across participants, while the order of tasks is fixed to reflect a consistent progression of task complexity (e.g., attribute-by-attribute comparison, overall pattern comparison).

5.1.1. *Visual Stimuli*

As shown in Figure 8, the three evaluated visualizations differ in geometry but preserve the same bilateral semantics and color assignments. Blossom Glyph (Figure 8C) encodes imports and exports as inward and outward petals, Diverging Bar Chart (Figure 8A) by left and right placement, and Grouped Radial Chart (Figure 8B) as grouped bars along distinct category axis. Legends were provided in the study interface. We used five dimensions to keep profiles compact while supporting meaningful multivariate comparison and preserving legibility as detailed in Section 3.3. Depending on task complexity, stimuli appeared as a single-country glyph or as multiples across countries or years. We used a geospatial setting because country-level trade data is naturally associated with map-based representations, letting participants assess both within-glyph profile structure and broader regional across-glyph patterns. The two baselines were selected as both can be extended to represent paired multivariate structure comparable to Blossom Glyph. Diverging Bar Chart serves as a familiar Cartesian baseline, while Grouped Radial Chart serves as a more closely related radial layout baseline. We considered radar chart and grouped polar area chart, shown in Figure 9, but did not include them in the study. In the radar chart, the two entities overlap to produce a region that can be perceived as an additional composite shape, thereby confusing users. In the grouped polar area chart, radial sectors grow in area with distance from

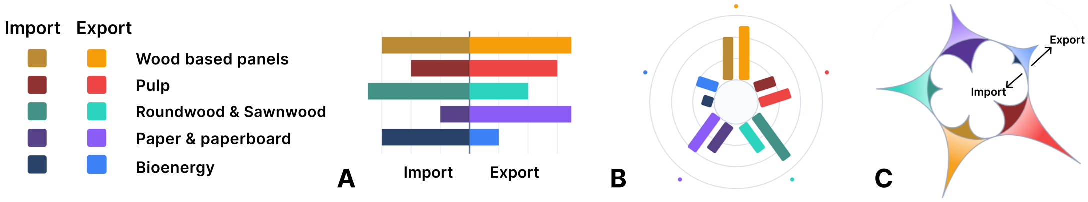


Figure 8.: Visual stimuli in the study. (A) Diverging Bar Chart. (B) Grouped Radial Chart. (C) Blossom Glyph. All representations encode the same five categories.

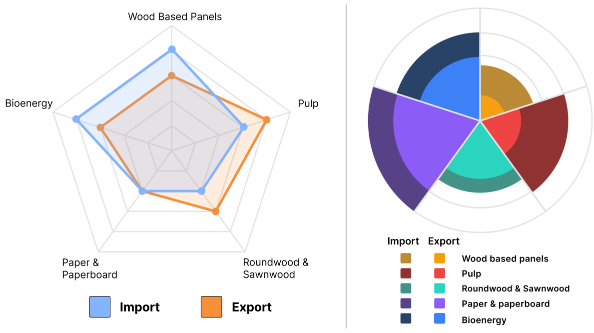


Figure 9.: Alternative visualizations considered during study design but not included in the study: radar chart (left) and grouped polar area chart (right).

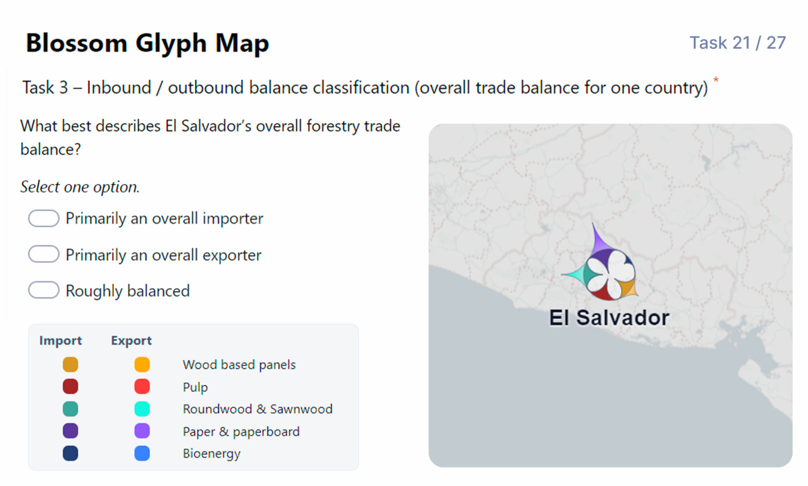
the center, promoting area-based interpretation rather than length-based reading emphasized in Blossom Glyph. For these reasons, neither alternative made the bilateral relationship or attribute-level comparison as explicit as the two chosen baselines.

5.1.2. Analytical Tasks

Table 1.: Nine analytical tasks in the comparative study showing each adapted low-level task, the multiple-choice question template shown to participants, and the primary analytic goal.

ID	**Low-Level Task**	**Question Template**	**Primary Analytical Goal**
1	Within-glyph extrema identification	For *[Country X]*, which wood-product category has the largest export value?	Focused attribute lookup and extremum detection within a single glyph.
2	Pairwise category comparison	For *[Country X]*, which category has greater exports: Roundwood & sawnwood or Paper & paperboard?	Direct comparison of two encoded magnitudes within one glyph.
3	Import-export balance assessment	What best describes *[Country X's]* overall forestry trade balance?	Holistic judgment of balance or asymmetry between imports and exports within one glyph.
4	Across-glyph dimension comparison	Focusing only on Wood-based panels, which country has the highest export?	Comparison of one category across multiple glyphs.
5	Aggregate glyph ranking	Which of the following countries is the strongest overall exporter of forestry products?	Comparison of multiple categories across multiple glyphs.
6	Pattern similarity matching	Which country has the most similar pattern of imports and exports to *[Country X]*?	Holistic glyph matching based on overall shape and relative structure.
7	Regional category summarization	Which wood-product category appears to be the least exported overall across *[Continent X]*?	Distributed attention and category-level summarization across multiple glyphs in a region.
8	Dimension-specific outlier detection	Focusing only on Roundwood & sawnwood, which country appears to be an outlier in forestry trade?	Anomaly detection of one category across multiple glyphs.
9	Temporal trend summarization	Considering *[Country X]* from *[2009 to 2012]* which statement best describes the overall pattern of forestry trade?	Sequential comparison and temporal synthesis using multiples over time.

Our task set is grounded in established visualization task taxonomies that identify low-level analytical tasks, including value retrieval, extremum finding, comparison, anomaly detection, and summarization (Amar et al., 2005; Brehmer & Munzner, 2013; Lee et al., 2006). We adapted these abstract task categories into domain-specific multiple choice questions for paired forestry trade data. These tasks were designed to assess whether Blossom Glyph, as a new representation for paired multivariate data,



Blossom Glyph Map

Task 21 / 27

Task 3 – Inbound / outbound balance classification (overall trade balance for one country) *

What best describes El Salvador's overall forestry trade balance?

Select one option.

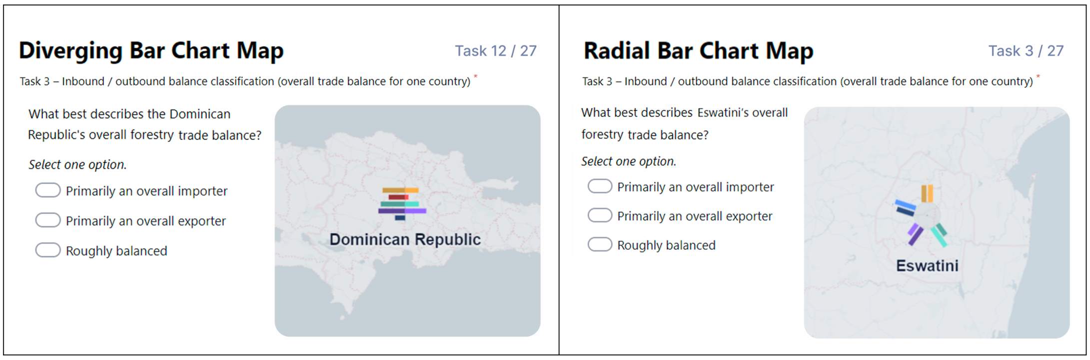
○ Primarily an overall importer

○ Primarily an overall exporter

○ Roughly balanced

Import	Export	
●	●	Wood based panels
●	●	Pulp
●	●	Roundwood & Sawnwood
●	●	Paper & paperboard
●	●	Bioenergy

Figure 10.: Task 3 (single-country trade-balance) in the Blossom Glyph condition.



Diverging Bar Chart Map

Task 12 / 27

Task 3 – Inbound / outbound balance classification (overall trade balance for one country) *

What best describes the Dominican Republic's overall forestry trade balance?

Select one option.

○ Primarily an overall importer

○ Primarily an overall exporter

○ Roughly balanced

Radial Bar Chart Map

Task 3 / 27

Task 3 – Inbound / outbound balance classification (overall trade balance for one country) *

What best describes Eswatini's overall forestry trade balance?

Select one option.

○ Primarily an overall importer

○ Primarily an overall exporter

○ Roughly balanced

Figure 11.: Task 3 in the baseline conditions: Diverging Bar Chart (left) and Grouped Radial Chart (right).

supports the same core analytical judgments as established baseline visualizations. Table 1 lists the nine tasks and their analytical goals.

Tasks 1–4 assess within-glyph reading by asking participants to interpret values and patterns within individual glyphs. Figure 10 shows a representative Task 3 screen from the Blossom Glyph condition, while Figure 11 shows the same task in Diverging Bar Chart and Grouped Radial Chart conditions. Together, these examples show how the same single-country balance assessment task can be implemented using different visualizations within a geospatial setting. These early tasks represent the simpler end of the task spectrum, focusing primarily on within-glyph reading before introducing broader contextual reasoning in later tasks. They test whether participants can visually locate a target attribute, compare a small number of magnitudes, and make a focused judgment within a single glyph. Although Task 4 involves multiple countries, the comparison remains limited to a single attribute, keeping attention focused on one dimension rather than requiring participants to synthesize multiple attributes or compare multiple glyphs.

Tasks 5–9 broaden the analytic scope from localized reading to across-glyph reasoning. These tasks require participants to compare multiple glyphs, integrate information across attributes, and reason about broader visual patterns. They therefore test how well each representation supports holistic entity interpretation and structural comparison under more distributed visual attention. Together, the nine tasks progress from direct attribute-level judgments to more integrative reasoning, allowing us to evaluate each visualization on both basic readability and higher-level tasks, e.g., similarity matching and trend interpretation. This progression is kept in the fixed task order.

5.2. Procedure

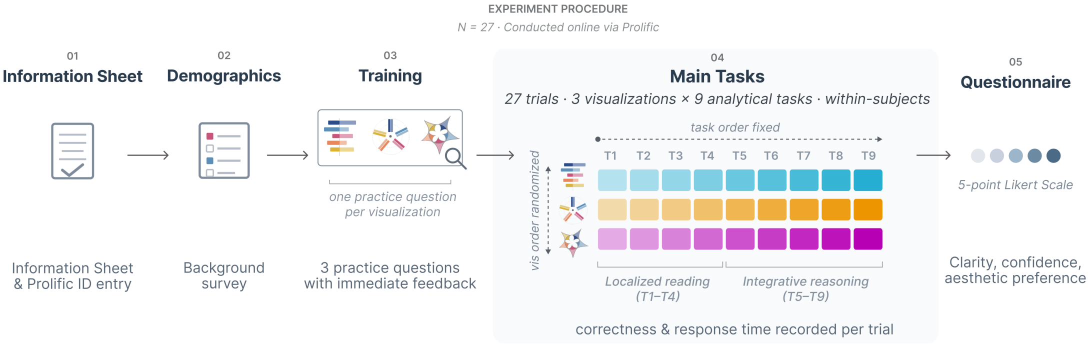


Figure 12.: Overview of the study procedure.

Participants completed the study online through Prolific, a crowdsourcing platform, following the procedure shown in Figure 12. The study protocol was reviewed and approved by Purdue University's Institutional Review Board (IRB #2025-00000043). After reviewing study information and entering their Prolific ID, participants completed a brief demographics survey followed by a short training session. The training session included three practice questions, one for each visualization type, designed to familiarize participants with the corresponding encoding through simple tasks. Immediate feedback was given after each response, indicating whether the answer was correct or incorrect and providing a brief explanation. Participants then completed the main task session. The order of the three visualization conditions was randomized to reduce order and learning effects. The task order within each visualization condition remained fixed, progressing from simpler, localized questions to interpretive and integrative ones. This structured progression allowed participants to become comfortable with each encoding before making more complex judgments. It also preserved a consistent task sequence across conditions. Each visualization condition contained the same set of nine tasks, implemented with specific visual stimuli but matched in underlying analytic objective. In total, each participant completed 27 trials. After the main task session, participants completed a brief post-study questionnaire that collected their overall impressions of three visualizations. The complete study took approximately 22 minutes (M = 21 min 45.7 s, SD = 8 min 9.3 s), and participants received a payment of $6.

5.3. Participants

Twenty-seven (27) participants were recruited through Prolific for the online study. Participants included 15 female and 12 male participants, with a mean age of 36.44 years (SD = 14.12). Eligibility was restricted using Prolific prescreening criteria to adults (≥ 18) residing in the United States and fluent in English. Before participating, participants were presented with an online information sheet and proceeded to the study by entering their Prolific IDs and clicking the "Continue" button, which served as an indicator of their willingness to participate. We did not obtain formal written or verbal consent because the study was conducted anonymously online, and only deidentified information was collected and analyzed. Prolific IDs were removed from the analysis dataset after quality checks and compensation.

6. Analyses and Results

We analyzed two objective measurements (i.e., correctness and completion time) and subjective ratings of four perceived interpretation aspects with respect to two primary experimental factors: visualization type and task type.

6.1. Statistical Methods

All data processing and statistical analyses were conducted using SAS® 9.4 and JMP® Pro 19. The SAS script is included in the supplementary materials. Because each participant completed all visualizations and task conditions, responses were analyzed using Generalized Linear Mixed Models (GLMMs) with participant as a random effect. Visualization type, task type, and their interaction were modeled as fixed effects. A general form of the model is

$$G(E(y_{ij})) = \beta_0 + \beta_1 x_{1ij} + \beta_2 x_{2ij} + \beta_3 x_{1ij} x_{2ij} + u_{0j}, \tag{1}$$

where y_{ij} is the response from participant j under condition i, x_1 denotes visualization type, x_2 denotes task type, and u_{0j} is a random intercept for participant j.

Correctness, coded as a binary response (*correct* = 1, *wrong* = 0), was analyzed using a GLMM with a binomial distribution and logit link. The model estimated the effects of visualization type, task order, and their interaction on the odds (i.e., probability) of a correct response. Pairwise comparisons among the three visualization types were then performed within each task type using least-squares means estimated from the fitted GLMM, which provide model-based estimates of the expected response for each visualization condition. These pairwise results are reported as odds ratios (ORs), indicating the relative likelihood of a correct response for one visualization type compared with another under the same task condition.

Completion time was measured for each trial as the elapsed time between webpage load and answer submission on a dedicated webpage. To ensure a more precise measurement of completion time, we disabled all other interactions by using static images and keeping only the radio and submission buttons. Each trial was designed to fit properly on a 14-inch laptop screen without requiring scrolling. Because the raw completion time data were positively skewed, we applied a Box-Cox transformation ($\frac{y^\lambda - 1}{\lambda}, \lambda = -0.341$). A goodness-of-fit test on the transformed data supported the normality assumption (Shapiro-Wilk: $W = 0.994$, $p = 0.484$). The transformed completion time data were then analyzed using a GLMM with a normal distribution using the same fixed- and random-effects structure as above. Pairwise comparisons among visualization types within each task were derived from the GLMM estimated least-squares means. Statistical significance was evaluated at $\alpha = 0.05$. We also compared the logarithmic and Box-Cox transformations using residual diagnostics and normal quantile (Q-Q) plots of the fitted GLMMs, which indicated that the Box-Cox transformation provided a better overall fit than the logarithmic transformation.

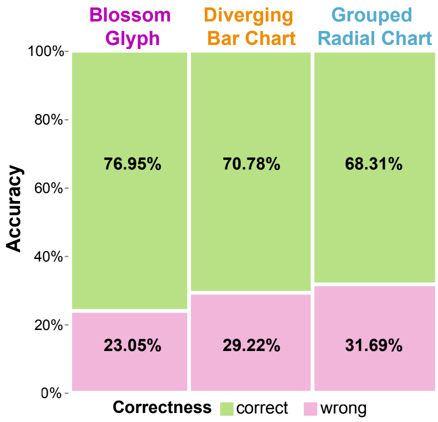
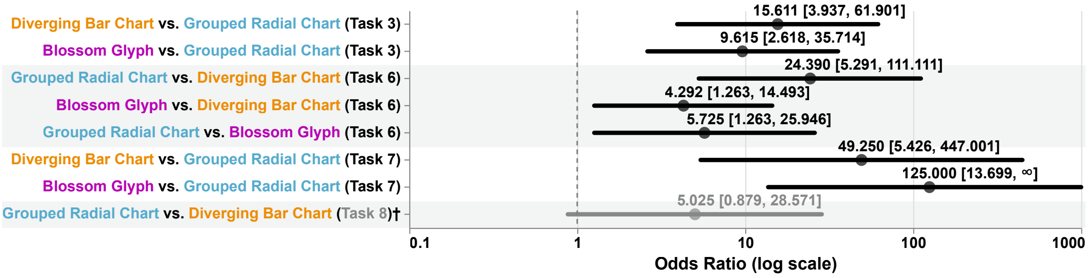


Figure 13.: Accuracy by visualization type. The mosaic plot summarizes the proportions of correct and incorrect responses for each visualization, computed from all responses collected across 27 participants and 9 tasks per visualization (243 trials = 27 × 9). Blossom Glyph yielded the highest accuracy (76.95%), followed by Diverging Bar Chart (70.78%) and Grouped Radial Chart (68.31%).



†marginally significance

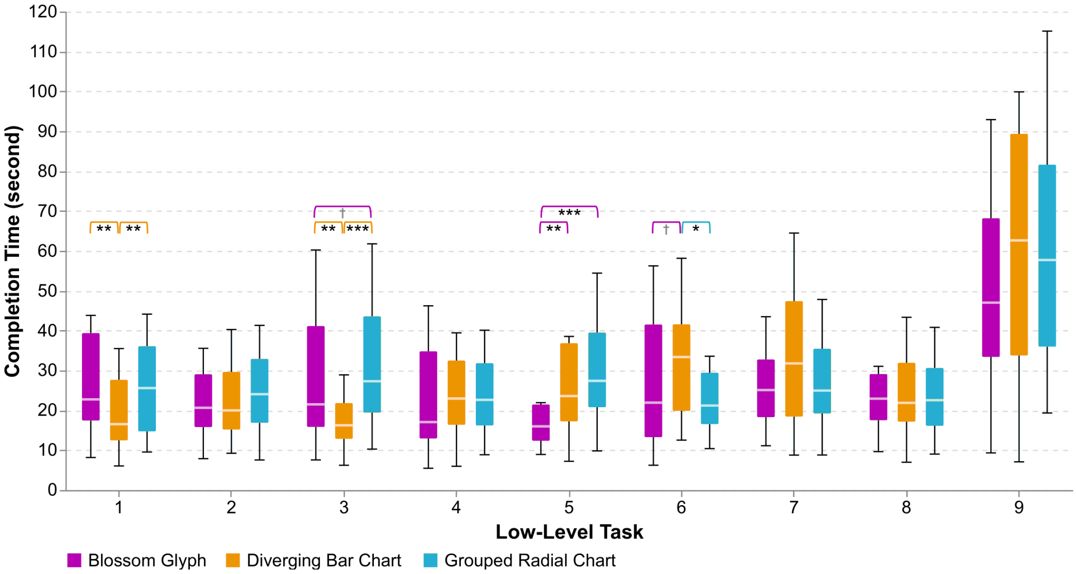
Figure 14.: Odds ratios of correctness for pairwise visualization comparisons in tasks showing statistically significant (Tasks 3, 6, 7; $p < 0.05$) or marginally significant differences (Task 8; $p < 0.10$). Dots show estimated ORs, and horizontal bars show 95% CIs on a log-scaled x-axis; numeric labels report raw OR values. ORs > 1.0 favor the first visualization in each pair, whereas ORs < 1.0 favor the second.

Furthermore, we conducted a post hoc power analysis to evaluate whether the current sample size (N = 27) was sufficient to support the significant effects identified by GLMMs. The analysis indicated a statistical power of 0.995 at $\alpha = 0.05$. To improve readability of results in the following subsections, Blossom Glyph, Diverging Bar Chart, and Grouped Radial Chart are color coded.

6.2. Correctness

As shown in Figure 13, Blossom Glyph achieved the highest accuracy (76.95% = 187/243), followed by Diverging Bar Chart (70.78% = 172/243), while Grouped Radial Chart showed the lowest accuracy (68.31% = 166/243).

Figure 14 shows the ORs of correctness for pairwise visualization comparisons with statistically significant or marginally significant differences. For Task 3, both Diverging Bar Chart (OR = 15.611 [3.937, 61.901], $p < 0.0001$) and Blossom Glyph (OR = 9.615 [2.618, 35.714], $p = 0.0007$) produced significantly higher chances of correct



†marginally significance $p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Figure 15.: Task completion time (seconds) across nine low-level tasks for three visualization types shown in boxplots. Tasks 1, 3, 5, and 6 have pairwise statistical significance differences or marginally significant differences.

responses than Grouped Radial Chart. For Task 6, Grouped Radial Chart significantly outperformed Diverging Bar Chart (OR = 24.390 [5.291, 111.111], $p < 0.0001$) and Blossom Glyph (OR = 5.725 [1.263, 25.946], $p = 0.0197$), and Blossom Glyph also outperformed Diverging Bar Chart (OR = 4.292 [1.263, 14.493], $p = 0.0237$). For Task 7, Diverging Bar Chart (OR = 49.250 [5.426, 447.001], $p = 0.0006$) and Blossom Glyph (OR = 125.000 [13.699, ∞], $p < 0.0001$) both showed substantially higher chances of correctness than Grouped Radial Chart. For Task 8, Grouped Radial Chart showed marginally higher odds of correct responses than Diverging Bar Chart (OR = 5.025 [0.879, 28.571], $p = 0.0695$).

6.3. Completion Time

Mean completion times were 32.864 seconds for Blossom Glyph, 32.767 seconds for Diverging Bar Chart, and 38.266 seconds for Grouped Radial Chart. Tukey HSD post hoc tests on the Box-Cox transformed completion time revealed a marginally significant difference between Blossom Glyph and Grouped Radial Chart ($p = 0.0785$), suggesting that Blossom Glyph tended to support faster task completion than Grouped Radial Chart. No reliable overall difference was observed between Blossom Glyph and Diverging Bar Chart.

Figure 15 shows completion times, in seconds, grouped by the nine tasks; within each group, completion times are compared across three visualization types. Pairwise comparisons based on the GLMM revealed significant differences in completion time for Tasks 1, 3, 5, and 6. For Task 1, Diverging Bar Chart (M = 21.466, SD = 13.364) was significantly faster than both Blossom Glyph (M = 33.687, SD = 28.346, $p = 0.0038$) and Grouped Radial Chart (M = 48.750, SD = 79.757, $p = 0.0043$). For Task 3, Diverging Bar Chart (M = 18.609, SD = 10.381) was again significantly faster than Blossom Glyph (M = 29.801, SD = 19.864, $p = 0.0013$) and Grouped Radial Chart (M

= 40.554, SD = 39.086, $p < 0.0001$); in addition, Blossom Glyph (M = 29.801, SD = 19.864) was marginally faster than Grouped Radial Chart (M = 40.554, SD = 39.086, $p = 0.0789$). For Task 5, Blossom Glyph (M = 22.777, SD = 20.847) was significantly faster than both Diverging Bar Chart (M = 32.538, SD = 25.377, $p = 0.0038$) and Grouped Radial Chart (M = 29.144, SD = 12.002, $p = 0.0009$). For Task 6, Grouped Radial Chart (M = 27.226, SD = 22.751) was significantly faster than Diverging Bar Chart (M = 34.514, SD = 17.224, $p = 0.0295$), and Blossom Glyph was marginally faster than Diverging Bar Chart ($p = 0.0537$). No significant or marginal differences were found for Tasks 2, 4, 7, 8, or 9.

6.4. Subjective Perceptions

The post study questionnaire included four items in a 5-point Likert scale for each visualization, covering (1) ease of reading, (2) learnability, (3) confidence, and (4) aesthetics. Diverging Bar Chart received the highest overall subjective ratings across the four items ($M = 4.40, SD = 0.52$), followed by Grouped Radial Chart ($M = 3.88, SD = 0.85$) and Blossom Glyph ($M = 3.09, SD = 0.98$). In addition, for each of the four subjective aspects, participants selected their most preferred visualization. These cross-visualization preference results were consistent with the Likert-scale ratings, with Diverging Bar Chart preferred most frequently overall.

To further contextualize these subjective preference results, we separately collected feedback from five design-domain expert participants who were shown the same three visualizations and asked to comment on aesthetic preference, readability, and visual form. This feedback was not part of the controlled crowdsourced study and is used as descriptive context rather than as part of the primary statistical analysis. Among the participants, three selected Blossom Glyph as their overall preferred visualization, while two selected Diverging Bar Chart. Several comments emphasized Blossom Glyph's visual identity and unified form. P2 described it as *"more soft and natural looking"* adding that *"it feels less technical and more like a icon."* Another participant similarly stated, *"I think it's [Blossom Glyph is] the one that feels like it has a visual identity."* At the same time, participants also noted constraints around density and tuning with P4 commenting that aesthetics *"depend a lot on spacing, labels, or amount of color"* and that with a high number of attributes *"it could become pretty dense quickly."* Comments on the Grouped Radial Chart were more consistently tied to visual complexity and interpretive effort. P3 stated, *"I know it's the same stats, but I just feel like there's a lot more information to digest here"*, while P5 questioned whether the design would become *"more hard to read"* with more than five categories.

7. Discussion

We discuss the implications of our analysis results in relation to the four research questions that guided the study.

7.1. Overall Effectiveness and Efficiency

In terms of effectiveness (**RQ1**) and efficiency (**RQ2**), the three visualizations exhibit distinct patterns across tasks. A visualization that performs well for within-glyph reading (Tasks 1–4) does not necessarily excel at across-glyph reading (Tasks 5–9). The subset of within-glyph reading tasks (Tasks 1–4) focuses more on simple attribute-level quantitative judgments. For completion time (Figure 15), Diverging Bar Chart is significantly faster than Blossom Glyph and Grouped Radial Chart for Tasks 1 (within-glyph extrema identification) and 3 (import-export balance assessment). In addition, for correctness (Figure 14), Diverging Bar Chart has significantly higher accuracy than Grouped Bar Chart but comparable performance to Blossom Glyph for Task 3. These results for within-glyph reading are consistent with graphical perception research showing that aligned position and length generally support more accurate and efficient quantitative judgments than angle, area, or contour-based visual channels (Cleveland & McGill, 1984). For Diverging Bar Chart, viewers compare values against a rectilinear layout, which reduces the need to interpret polar coordinates, curvature, or enclosed shape before making a decision. This likely explains why the bar baseline remained especially effective for tasks centered on attribute-level magnitude comparison for within-glyph reading. In contrast, both radial layouts require extra interpretation of radial length and overall shape, even when the task itself is merely within-glyph reading.

Conversely, for across-glyph reading (Tasks 4–9), radial layout glyphs achieved higher accuracy and faster completion time for most cases. For completion time, Blossom Glyph is significantly faster than Diverging Bar Chart for Tasks 5 and 6. For correctness, Blossom Glyph has significantly higher accuracy than Diverging Bar Chart for Task 6; Grouped Radial Chart has marginal significance than Diverging Bar Chart for Task 8. Results for across-glyph reading are consistent with prior work that radial layout is better for comparison of a large number of glyphs (Keck et al., 2017).

The results would be unsurprising if we concluded that rectilinear layouts are better suited for within-glyph reading, whereas radial layouts are better suited for across-glyph comparison. The more notable finding is that Blossom Glyph performs competitively in both settings: it achieves comparable performance to the Diverging Bar Chart for within-glyph reading and matches, or even exceeds, the Grouped Radial Chart for across-glyph comparison. This suggests that Blossom Glyph's performance is not simply a consequence of its radial layout, but also reflects more nuanced perceptual effects arising from its visual encodings and design principles.

7.2. Structural Cues for Balance

Results from tasks centered on relational balance demonstrate a key functional advantage of the Blossom Glyph: its ability to make paired data structures visually explicit. In Task 3 (trade balance assessment), both the Blossom Glyph and the Diverging Bar Chart achieved significantly higher accuracy than the Grouped Radial Chart. This trend extended to Task 7 (regional category summarization), where the radial baseline again underperformed. These tasks require viewers to assess how paired values relate to one another within a shared structure, either within a single country or across multiple glyphs in a region. We interpret this as evidence for the importance of a clear structural anchor for successful interpretation of paired multivariate data for across-glyph reading.

The results validate the design principles of **Symmetry and Equilibrium** established in Section 3. By positioning bilateral values in opposing directions along the same angular axis, Blossom Glyph transforms symmetry and asymmetry into immediate visual cues for relational balance. A more balanced profile produces a more visually centered contour, whereas a strongly inward or outward dominant profile produces a recognizably skewed representation. Furthermore, the principle of **Typedness** is achieved through directional polarity, where the global shape serves as a visual category. This allows users to immediately identify the "type" of trade relationship, such as balance or one-sided dominance, based on the silhouette's characteristic.

These results align with results from balance-oriented glyph research, which demonstrates that symmetric structures materially improve judgments of equilibrium and imbalance (Koc et al., 2022). Our observations are also consistent with psychological literature establishing symmetry as a highly salient organizational cue that supports rapid grouping and figure-ground interpretation (Palmer, 1999; Wagemans et al., 2012). In contrast, Grouped Radial Chart lacks a mechanism to utilize symmetry as an informative signal. The visualization requires users to serially compare adjacent bars to mentally reconstruct the balance relationship, increasing cognitive load and the probability of separable processing errors during both within-glyph inspections and across-glyph regional scans (Wickens & Carswell, 1995). Task 7 is especially important in this regard. The regional summarization task required viewers to constantly compare multiple glyphs and all attributes to visually locate the attribute with the least export. Task 7 placed heavier demands on distributed attention than Task 3. The fact that Blossom Glyph remained competitive (significantly higher accuracy than Grouped Radial Chart, comparable accuracy to Diverging Bar Chart in Figure 14) here suggests that its bilateral organization does more than support single-glyph balance judgments; it also helps preserve structural readability when the display is scalable to multiple glyphs. Thus, **RQ3** is answered not just by performance on pattern matching, but also by Blossom Glyph's ability to sustain balance-oriented reasoning across-glyph regional comparison.

7.3. Across-Glyph Reading and Holistic Comparison

Integrative tasks, which require participants to compare multiple glyphs and synthesize information across attributes, provide the strongest test of Blossom Glyph's central design goal: supporting holistic interpretation of paired multivariate data. For Task 5 (aggregate glyph ranking), Blossom Glyph was significantly faster than both baselines. This suggests that participants could use the integrated contour as a compact visual summary rather than serially aggregating independent values. This result aligns with the design principles of **Searchability**, **Readability**, and **Contextual Stability** (Borgo et al., 2013; Fuchs et al., 2017). The glyph's design allows dominant entities to stand out visually where the overall "fullness" of the petals can be grasped as an aggregate cue and contour remains recognizable across entities without requiring repeated structural learning. It also highlights an important relationship between speed and accuracy. In many experimental settings, improved accuracy comes at the cost of longer response times, reflecting a well-established speed–accuracy tradeoff in human decision making (Heitz, 2014; Wickelgren, 1977). However, Blossom Glyph, showed an advantage on integrative tasks. Although Diverging Bar Chart was the fastest overall for within-glyph tasks, Blossom Glyph performed better on across-glyph tasks without a significant time penalty (**RQ2**).

Task 6 (pattern similarity matching) produced a more nuanced result. For accuracy, both Blossom Glyph and Grouped Radial Chart outperformed Diverging Bar Chart, but Grouped Radial Chart was also significantly more accurate than Blossom Glyph. For completion time, Blossom Glyph and Grouped Radial Chart were both significantly faster than Diverging Bar Chart, with no significant difference between the two radial designs. Together, these findings suggest that profile matching benefits from displays that preserve stable global shape, which is more difficult in a fragmented bar-based encoding. They also follow the *Proximity Compatibility Principle*, which argues that tasks requiring high mental integration are better supported when related information is brought into closer perceptual proximity (Wickens & Carswell, 1995). In this sense, Blossom Glyph carries an advantage over the rectilinear bar baseline because it couples bilateral attributes into a single Gestalt form, reducing the mental integration required across separated elements. As described in Section 3, the Bézier-based construction creates smooth, continuously tangent borders between radial axes. Under the law of closure, such bounded contours are more likely to be perceived as stable wholes rather than disconnected parts (Wagemans et al., 2012). In contrast, Diverging Bar Chart requires viewers to compare ten bars per entity, creating a more fragmented comparison space.

The performance of Grouped Radial Chart is also revealing beyond its advantage in Task 6. Across the study it was often slower or less accurate, especially for balance and regional tasks, which suggests that the radial coordinate system alone does not guarantee good performance. Rather, its benefits appear when the design supports stable correspondence, symmetry, and grouped closure in ways that align with the task. From this perspective, Blossom Glyph can be understood as a refinement of radial layout: a design that retains radial compactness while making paired structure and balance more immediately legible.

7.4. The Performance-Preference Paradox

Despite significantly higher accuracy and faster completion time on some tasks, most participants still preferred Diverging Bar Chart in subjective ratings of ease of use, aesthetic preference, and overall confidence (**RQ4**). We interpret this through the *Mere Exposure Effect* (Zajonc, 1968) and the broader dissociation between performance and preference (Hertzum, 2025). Viewers likely possess a stronger and more immediate mental model for Cartesian charts, which can produce higher subjective confidence even for tasks performed with lower accuracy. Blossom Glyph appears to carry a short-term learning cost associated with novelty. This does not negate the performance results; rather it suggests that subjective preference may reflect familiarity, interpretive confidence, and prior chart literacy in addition to objective task success. Therefore, adoption of a new glyph may depend not only on its analytic merit, but also on whether users are given enough exposure and context to build trust in the representation (Norman, 2013). To contextualize the subjective ratings, we conducted interviews with five designers about their perceptions of Blossom Glyph and two baseline visualizations. Detailed information about the designers' backgrounds and selected comments is included in the supplementary materials. A common pattern across designers was that they did not only evaluate aesthetics in terms of immediate clarity, but also in terms of visual form and representational identity. For example, P2 noted that *"the [Blossom Glyph's] visual appearance is not separate from the information part."* P4 commented that *"I think [Blossom Glyph is] the one that feels like it has a visual identity. The bar chart is maybe clearer, but it feels like a default chart. The [Blossom Glyph] is like a visual form, not just a chart. It's nice that it's recognizable like that."* Overall, responses suggest that Blossom Glyph's aesthetic contribution lies not merely in immediate preference, but in how it integrates paired multivariate data for comparison, recognizability, and data meaning within a compact visual form.

8. Conclusion

We introduce Blossom Glyph, a compact visualization for relational visualization of paired multivariate data that supports both within-glyph and across-glyph reading. Through a comparative crowdsourced study against Diverging Bar Chart and Grouped Radial Chart, the results revealed a task dependent performance landscape rather than a single superior visualization. Blossom Glyph does not outperform both baselines across all tasks, but it shows advantages in facilitating high-level integrative judgments while remaining competitive on several other tasks, such as within-profile lookup or extrema identification. The results also show the practical significance of design principles detailed in Section 3.2. They suggest that effective glyph design for paired multivariate data depends on **balancing local readability with holistic structure**. In Blossom Glyph, symmetry and equilibrium, directional affordance, and Gestalt coherence function as mechanisms that make balance, dominance, and profile similarity visually discernible. Together with case studies, these findings position Blossom Glyph as a flexible addition to the design space for paired multivariate comparison.

Data Availability

The data and materials supporting the findings of this study are publicly available in the GitHub repository at `https://github.com/THENABINKHANAL/BlossomGlyph.git`. The repository includes the source code for generating Blossom Glyph, screenshots of the online study webpages, raw correctness and response time data, raw subjective rating data, SAS analysis scripts, GLMM analysis results, and anonymized designer feedback.

Author Contributions

Sundas Qaiser contributed to the conceptualization and design of the work, methodology, investigation, data curation, validation, visualization, drafting of the manuscript, and critical revision of the manuscript. Nabin Khanal contributed to the methodology, investigation, software development, visualization, formal analysis and interpretation of the data, drafting of the manuscript, and critical revision of the manuscript. Jieqiong Zhao contributed to the methodology, data curation, validation, formal analysis and interpretation of the data, and critical revision of the manuscript. Yingjie Victor Chen contributed to the conceptualization and design of the work, project administration, supervision, and critical revision of the manuscript. Cheryl Zhenyu Qian contributed to the conceptualization and design of the work, project administration, supervision, and critical revision of the manuscript. All authors approved the final version to be published and agree to be accountable for all aspects of the work.

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