Field-Consistent Glyphs

Advanced Software Practical

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Motivation

Motivation & Problem Statement

- Traditional arrow glyphs depict a local vector only at the arrow's base
- In curved or complex fields, a single straight arrow can be misleading because the arrow shaft does not follow the field's actual curvature
- Tensor fields are even more challenging because they encode multiple directions and magnitudes at each point

Project Goals

Objectives

- Develop methods to create glyphs that follow the local field throughout their geometry
- Implement filters in ParaView using Python
- Explore both 2D vector fields and 3D tensor fields

Related Work

Related Work – Overview

Focus: Enhancing **clarity**, **perception**, and **accuracy** of glyphs for flow representation

Featured Works:

- *Flow Radar Glyphs* (Hlawatsch et al., 2011) [1]
- *Hairy Slices* (Stevens et al., 2017) [3]
- *Streamlines with Glyphs* (Pilar & Ware, 2013) [2]

Flow Radar Glyphs [1]

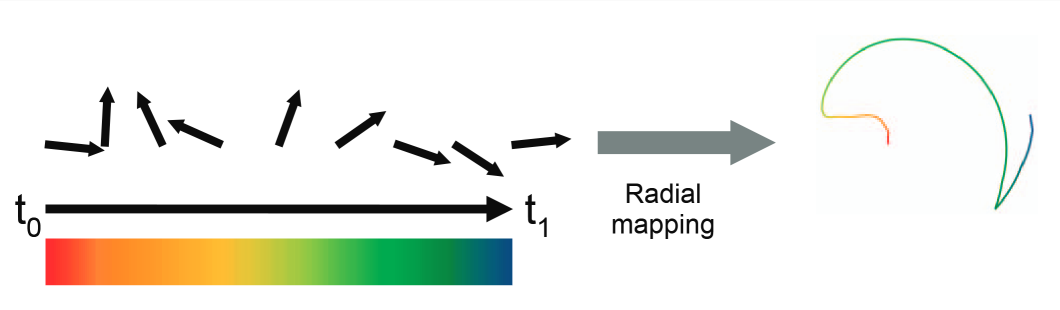
Key Idea: Static glyphs visualizing unsteady, time-dependent flow & uncertainty

- Glyph shape encodes time evolution of flow (direction = angle, time = radius)
- Multi-scale visualization: works for global (overview) and local (details) levels
- Helps compare different time steps without animation

Relevance to this work:

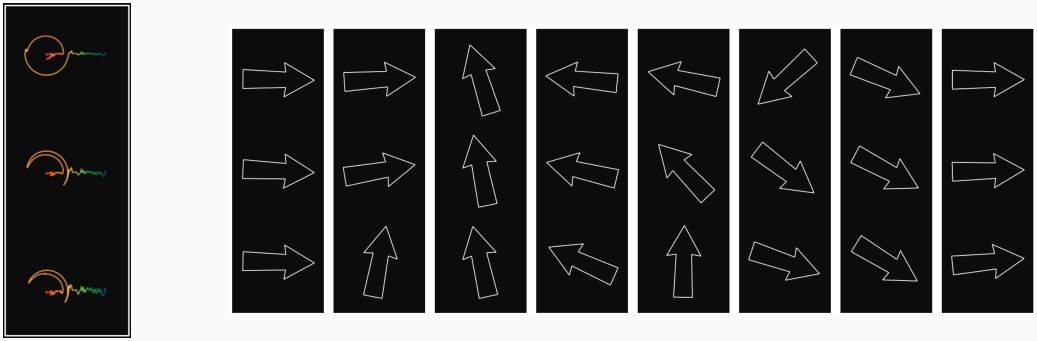
- Uses a type of field-consistent glyph (detailed level)
- Idea of spatial & temporal clarity

Flow Radar Glyphs [1]



Overview of the construction of flow radar glyphs. Direction gets mapped to the angle and time to the radius. Colormapping is used to further emphasize the temporal behavior. (Image from [1])

Flow Radar Glyphs [1]



Flow radar glyphs (left) compared to an animation of classic vector glyphs (right)
(Images from [1])

Hairy Slices [3]

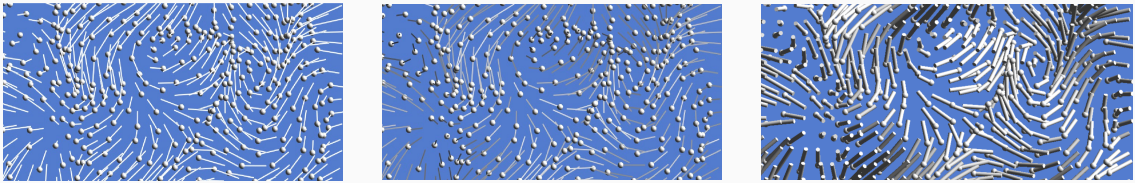
Key Idea: Evaluating 3D vector glyph designs on cutting planes

- Compared thin line glyphs to 3D tube glyphs for directional clarity
- Shading to improve depth perception
- Tube glyphs (thicker, shaded) helped users judge flow direction
- Works well for slicing 3D vector fields

Relevance to this work:

- Shows importance of shading and depth cues for 3D visualization
- Informs how to make glyphs perceptually clear

Hairy Slices [3]



Three glyph visualization techniques evaluated in [3]; plain lines, illuminated lines, and plain tubes. (Images from [3])

Streamlines with Glyphs [2]

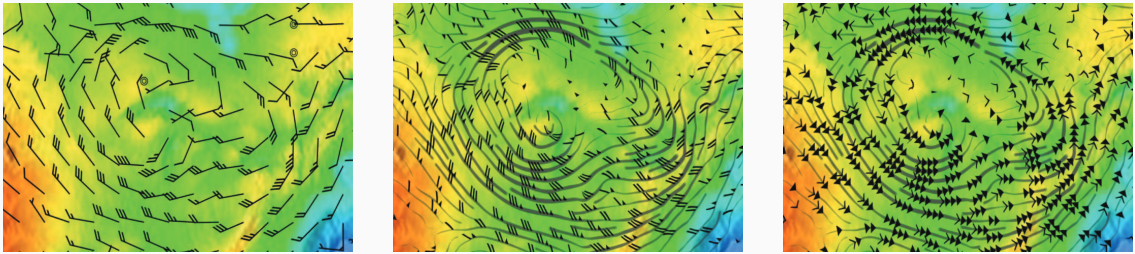
Key Idea: Combining streamlines with glyphs for clearer flow patterns

- Arrows along streamlines $\rightarrow$ eliminates direction ambiguity
- Encoding speed: Glyph shape & spacing reflects flow magnitude
- Improves perception of continuous flow vs. scattered arrow grids
- Challenge: Glyphs can overlap in dense fields

Relevance to this work:

- Field consistency $\rightarrow$ glyphs follow streamlines

Streamlines with Glyphs [2]



The classic wind barbs on the left, modified classic wind barbs on streamlines in the middle, and new arrow glyph design on streamlines on the right. (Images from [2])

Fundamentals

Euler's Method

$$\mathbf{p}_{n+1} = \mathbf{p}_n + h\mathbf{v}(\mathbf{p}_n)$$

RK4

$$\mathbf{k}_1 = \mathbf{v}(\mathbf{p}_n), \quad \mathbf{k}_2 = \mathbf{v}(\mathbf{p}_n + \frac{h}{2}\mathbf{k}_1), \quad \mathbf{k}_3 = \mathbf{v}(\mathbf{p}_n + \frac{h}{2}\mathbf{k}_2), \quad \mathbf{k}_4 = \mathbf{v}(\mathbf{p}_n + h\mathbf{k}_3)$$

$$\mathbf{p}_{n+1} = \mathbf{p}_n + \frac{h}{6}(\mathbf{k}_1 + 2\mathbf{k}_2 + 2\mathbf{k}_3 + \mathbf{k}_4).$$

where h is the step size and $\mathbf{v}(\mathbf{p})$ is the velocity field.

Bilinear Interpolation

For a grid with corners $(x_1, y_1), (x_2, y_2)$ and a function f, for a point (x, y) inside, we define:

$$\alpha = \frac{x - x_1}{x_2 - x_1}, \quad \beta = \frac{y - y_1}{y_2 - y_1}$$

Then:

$$f(x, y) = (1 - \alpha)(1 - \beta) f(x_1, y_1) + \alpha(1 - \beta) f(x_2, y_1) + (1 - \alpha)\beta f(x_1, y_2) + \alpha\beta f(x_2, y_2)$$

Bezier Splines

A cubic Bezier curve with control points $\mathbf{P}_0, \mathbf{P}_1, \mathbf{P}_2, \mathbf{P}_3$ is given by:

$$\mathbf{B}(t) = (1-t)^3\mathbf{P}_0 + 3t(1-t)^2\mathbf{P}_1 + 3t^2(1-t)\mathbf{P}_2 + t^3\mathbf{P}_3, \quad t \in [0,1]$$

Bisection Method

For a function $f(\alpha)$ for which we want $f(\alpha) = 0$:

- Start with an interval $[\alpha_a, \alpha_b]$
- Compute the midpoint $\alpha_m = \frac{\alpha_a + \alpha_b}{2}$
- Depending on evaluation criteria, replace one interval endpoint with α_m
- Repeat until convergence criteria met

Eigenvalue & Eigenvector Computations

For a tensor $\mathbf{T}$, solve $\mathbf{T}\mathbf{v} = \lambda\mathbf{v}$

λ are the eigenvalues, $\mathbf{v}$ the corresponding eigenvectors

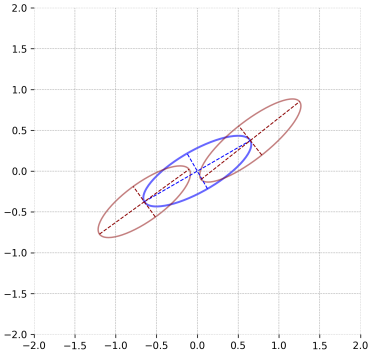
Method

Tensor Field Glyphs

Original plan: chain ellipsoidal glyphs so that the major axis of one is the seed for the next

Challenges: No field-consistent convergence criteria found, visually cluttered and complex

Eventually decided to shift focus to 2D vector fields



Overview of Arrow Construction Pipeline

1. **Seed Points** on a grid (or user-defined)
2. **Trace the main streamline** forward and backward from the seed
3. **Trace orthogonal streamlines** to form width of the arrow base
4. **Create arrow sides** by tracing forward from the base endpoints
5. **Close the arrowhead** using one of several strategies

Arrowhead Variants

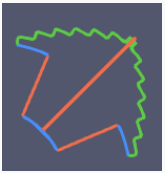
- **Smooth Arrowhead:** weighted combination of parallel and orthogonal field
- **Starcase Arrowhead:** alternating parallel and orthogonal steps
- **Bezier/Interpolated approach:** control points from the field, but final shape not field following

Smooth Arrowhead

Proposed ”field-consistent” arrow glyph. Red lines are parallel to the field, blue lines are orthogonal to the field, and green lines follow weighted combination of parallel and orthogonal field.

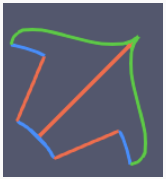
Arrowhead Variants

Staircase Arrowhead



Proposed ”field-consistent” arrow glyph. Red lines are parallel to the field, blue lines are orthogonal to the field, and green lines follow alternating parallel and orthogonal steps.

Bezier/Interpolated approach

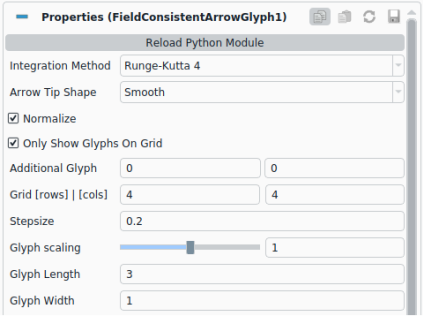


Proposed ”field-consistent” arrow glyph. Red lines are parallel to the field, blue lines are orthogonal to the field, and green lines follow Bezier spline with control points from the field.

Key Parameters

User definable Parameters in ParaView:

- **Integration method** (Euler vs. RK4)
- **Arrowhead shape** selection
- **Normalization** vs. real magnitudes
- **Grid resolution** how many glyphs $n \times m$
- **Additional Glyph** construction at point
- **Stepsize** affects curvature detail
- **Scaling** extra factor like step size
- **Length & Width** dictate arrow length & width



ParaView ”properties” panel for the new glyph filter.

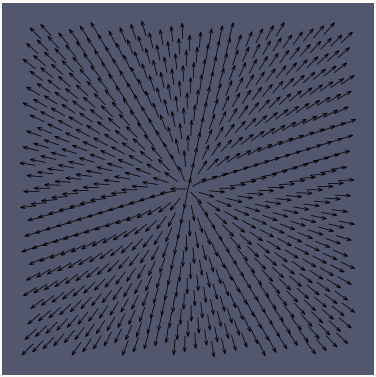
Results

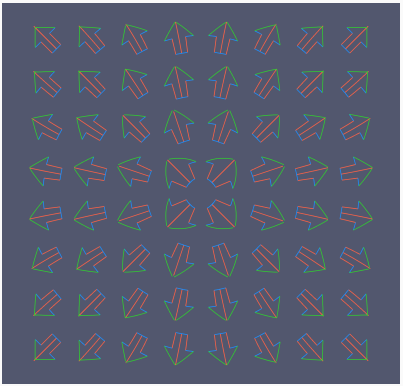
Example Fields

Field Examples:

- **Radial Field** $F = (x, y)$
- **Rotational Field** $F = (-y, x)$
- **Saddle Field** $F = (x, -y)$

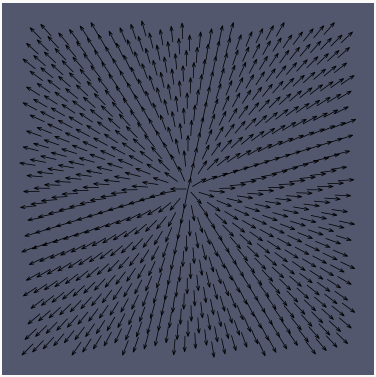
Radial Field Comparison

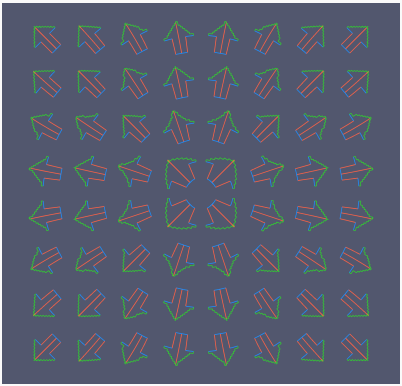




Comparison between classical arrow glyphs (left) and our proposed field-consitent arrow glyphs (right) with a smooth arrow tip in a radial field.

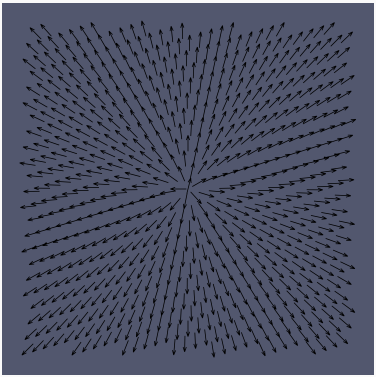
Radial Field Comparison

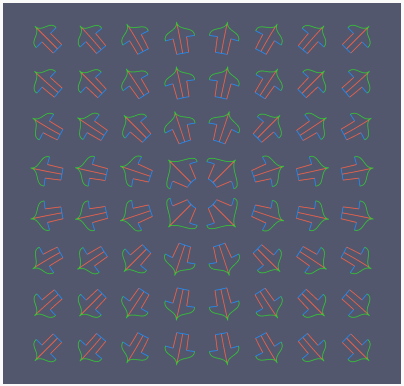




Comparison between classical arrow glyphs (left) and our proposed field-consitent arrow glyphs (right) with a jagged, staircase arrow tip in a radial field.

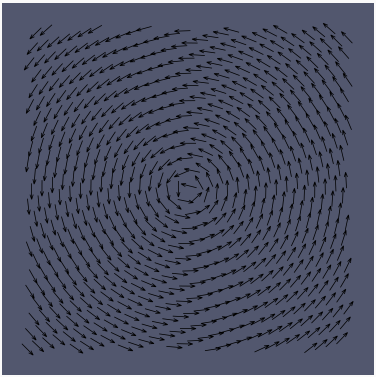
Radial Field Comparison

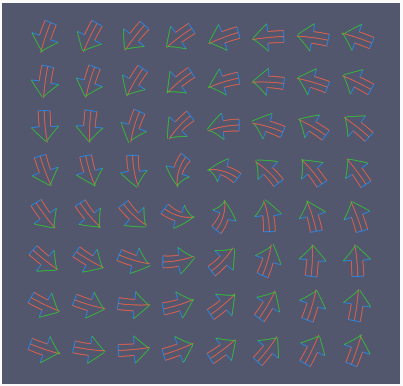




Comparison between classical arrow glyphs (left) and our proposed field-consitent arrow glyphs (right) with an interpolate arrow tip in a radial field.

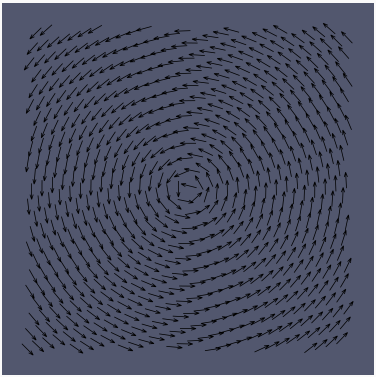
Rotational Field Comparison

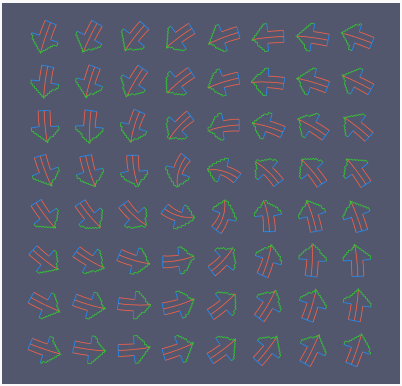




Comparison between classical arrow glyphs (left) and our proposed field-consitent arrow glyphs (right) with a smooth arrow tip in a rotational field.

Rotational Field Comparison





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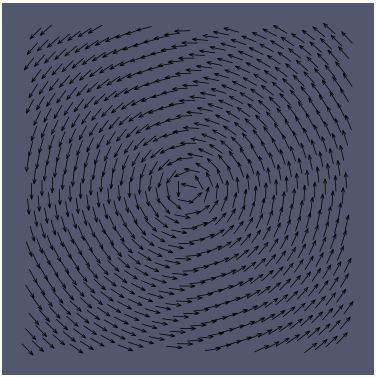
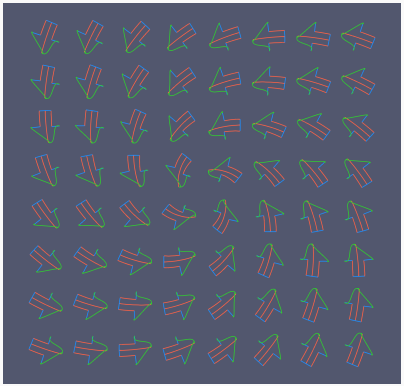
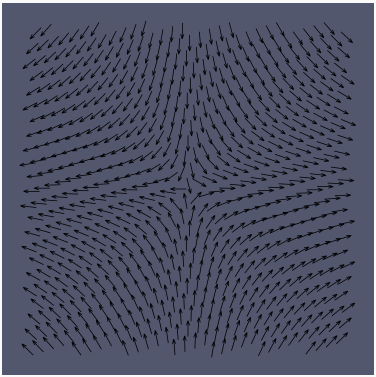
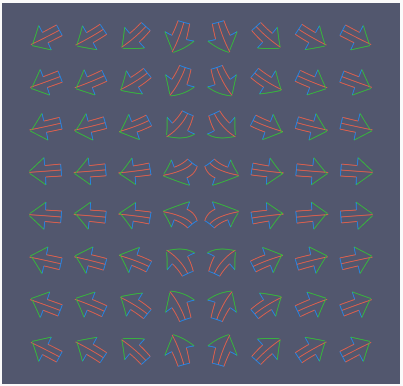




Comparison between classical arrow glyphs (left) and our proposed field-consitent arrow glyphs (right) with an interpolate arrow tip in a rotational field.

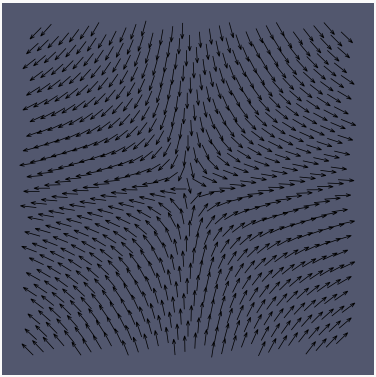
Saddle Field Comparison

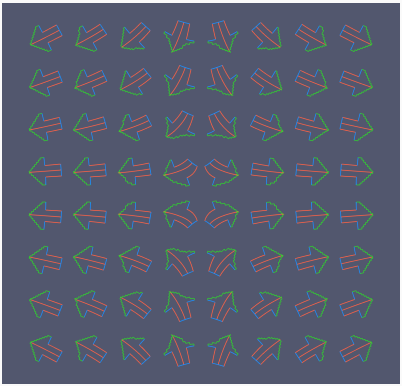




Comparison between classical arrow glyphs (left) and our proposed field-consitent arrow glyphs (right) with a smooth arrow tip in a saddle field.

Saddle Field Comparison





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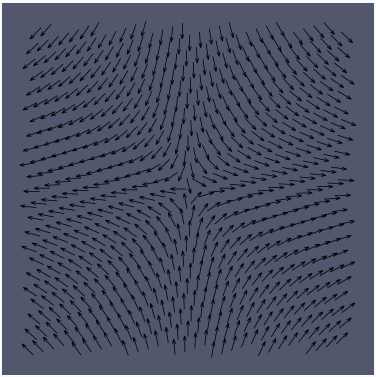
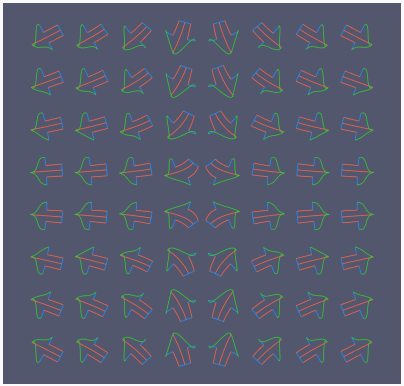
Saddle Field Comparison





Comparison between classical arrow glyphs (left) and our proposed field-consitent arrow glyphs (right) with an interpolate arrow tip in a saddle field.

Interpretation vs. Performance

- Field-consistent glyphs are **more informative** but **cost more** to compute
- Straight arrows are **cheaper** to render but can be misleading in curved fields

  $\rightarrow$ Require higher number of arrows to convey equal amount of information
- Possibility to mitigate computational cost with **adaptive seeding** or **interactive** parameter changes

Future Work

Potential Extensions

- **Topological Placement:** adaptive density near critical points or regions of high
- **3D Extension:** similar construction pipeline, more complex geometry, occlusion problems
- **Time-Dependent Fields:** animate glyphs or embed time info in glyph shape
- **Uncertainty Visualization:** show variance or confidence intervals with color or shape
- **User Interaction:** real-time seed placement
- **Parallelization** of line tracing in arrow construction

Conclusion

Summary

- **Field-consistent glyphs** reduce ambiguity by truly following the field
- **Trade-Off:** improved clarity vs. higher computation
- **Future:** adapting methods to 3D, time-varying data, or topological optimization

References

[1] Marcel Hlawatsch et al. **“Flow Radar Glyphs—Static Visualization of Unsteady Flow with Uncertainty”.** In: *IEEE Transactions on Visualization and Computer Graphics* 17.12 (2011), pp. 1949–1958. DOI: 10.1109/TVCG.2011.203.

[2] David H.F. Pilar and Colin Ware. **“Representing Flow Patterns by Using Streamlines with Glyphs”.** In: *IEEE Transactions on Visualization and Computer Graphics* 19.8 (2013), pp. 1331–1341. DOI: 10.1109/TVCG.2013.10.

[3] Andrew H. Stevens, Thomas Butkiewicz, and Colin Ware. **“Hairy Slices: Evaluating the Perceptual Effectiveness of Cutting Plane Glyphs for 3D Vector Fields”.** In: *IEEE Transactions on Visualization and Computer Graphics* 23.1 (2017), pp. 990–999. DOI: 10.1109/TVCG.2016.2598448.