Scientific Visualization
Part 3: Vectors/Directions

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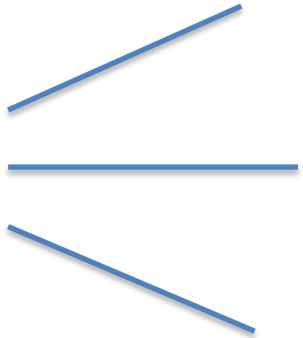
Vector Data (2D/3D)

- It is common for scientific data to have measurements of velocity
  - e.g. Fluid Dynamics
  - e.g. Weather Data
  - e.g. Signal Propagation (brain)
- Need to understand the overall flow of velocity data
- Note: can also have vectors of other values; here we focus on flow, where vectors are velocity measurements

The Three Aspects of a Vector

- Magnitude
  (speed)

- Orientation



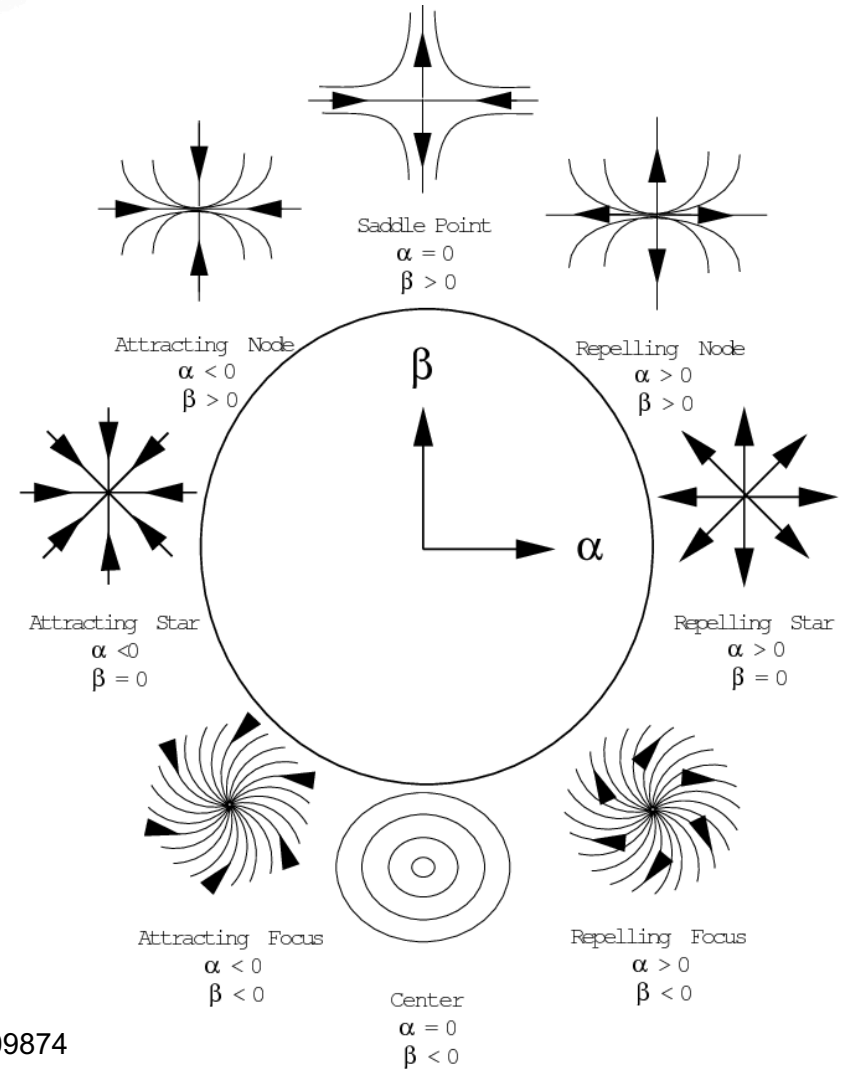
- Direction
  (usually)

Vector Visualization Tasks

- Judging speed, orientation, direction at an arbitrary point
- Identifying critical points (0 velocity)
  - Of various types (next slide)
- Judging advection trajectory
- Perceiving patterns of high/low speed
- Perceiving patterns of high/low vorticity
  - (as opposed to laminar flow)
- Perceiving patterns of high/low turbulence

Critical Points (in 2D Vector Field)

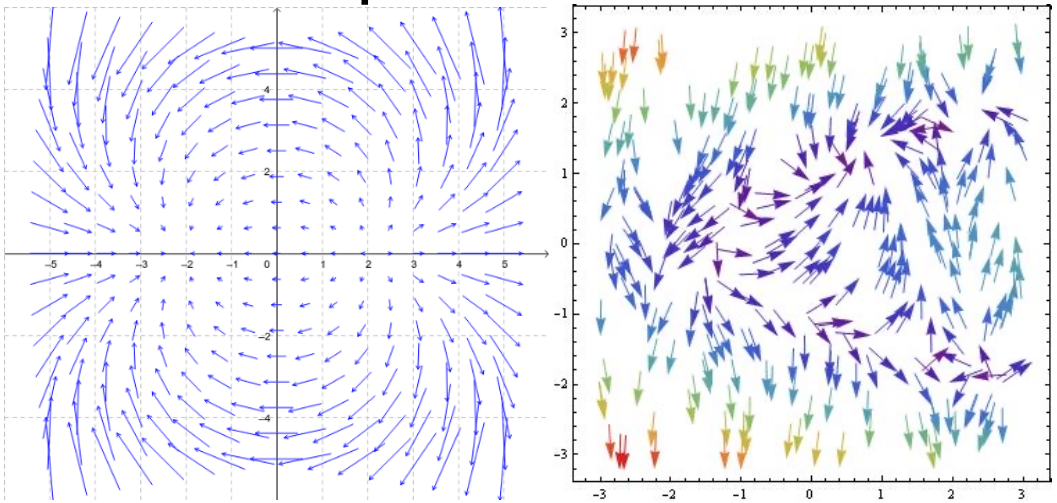
- Critical Points are 0 velocity points
  - And streamlines are not parallel
- Defines local topology
- Global topology from connecting critical points
- Types are defined by eigenvalues of Jacobian of velocity field



From: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=809874

Common Visualization Approaches

- Draw lines, glyphs, etc. that show the orientation/magnitude/direction
  - But not always all three
- Perceptual issue: Glyphs in rows/columns
  - Tends to create artificial patterns
  - Random or jitter reduce effect



From: https://www.geogebra.org/m/QPE4PaDZ
https://www.wolfram.com/mathematica/newin7/content/VectorAndFieldVisualization/PlotFieldVectorsAtRandomPositions.html

2D vs. 3D

- 2D vector field visualizations have common features
  - Visual contours (lines connecting flow in one place to another location)
- 3D vector fields have two complications
  - Vectors themselves are in 3D
  - Vectors are arranged spatially in 3D
    - Thus we face occlusion issues as seen earlier in visualizing geometry
    - Stronger need to reduce clutter, overdrawing, etc.

Perceptual Effects: Orientation

- Visual contour lines should be extended along flow orientation
- If there are individual segments, should be able to visually connect them into contours

Perceptual Effects: Magnitude

- Higher perceptual response can be used to indicate greater magnitude
  - Longer
  - Wider
  - Higher Contrast
  - Higher motion (if animated)

Perceptual Effects: Direction

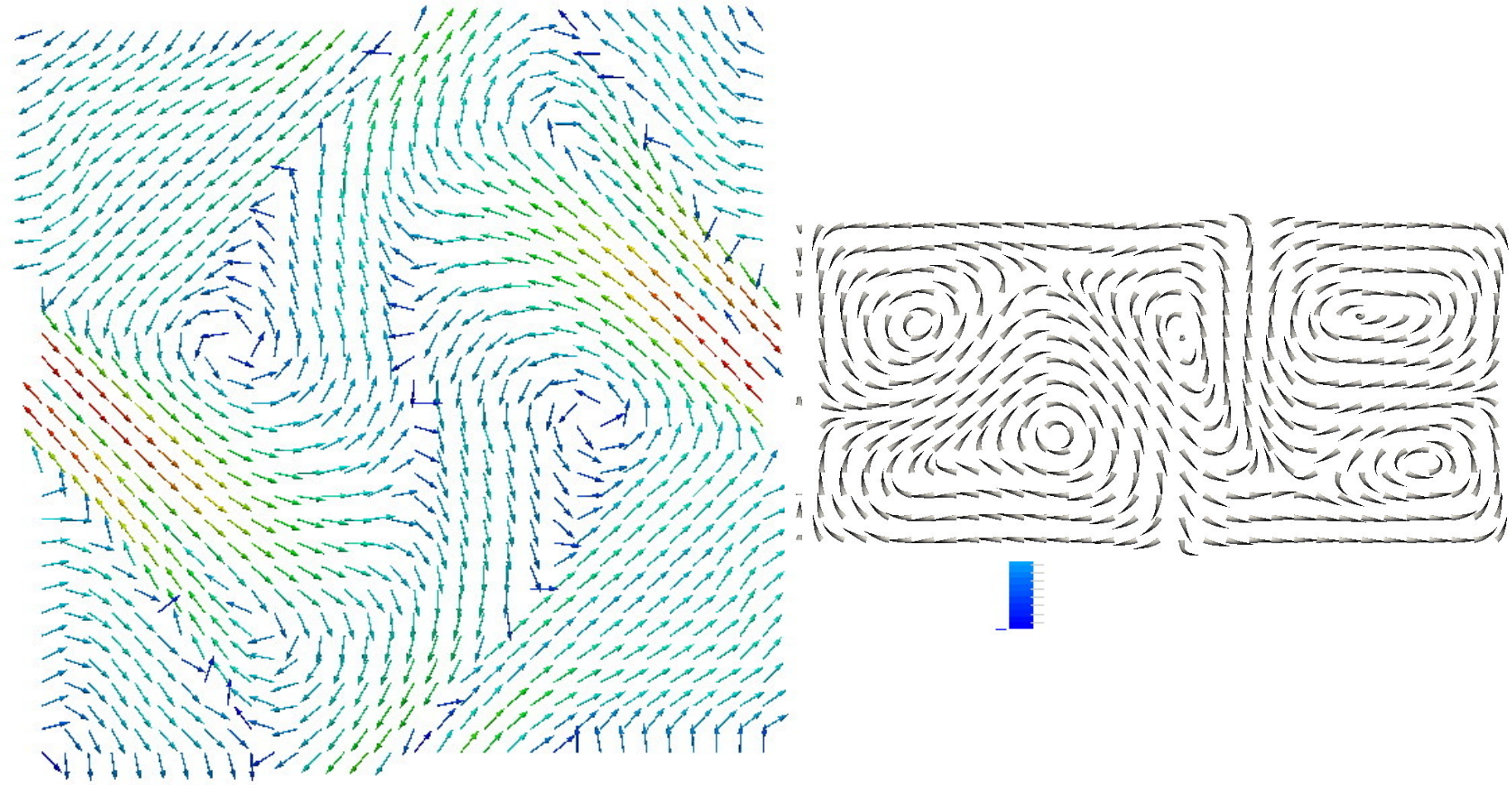
- Neural response: endpoints of segments are noticed
  - Contour ending in visual field
  - Strength determined by level of contrast
- For direction, something needs to be added to give asymmetry.
  - Head should be more distinct than tail
  - Higher luminance contrast vs. lower

Visualization Methods

Glyphs (Hedgehog plots)

- Basic idea: draw a symbol/shape at points where velocity is known.
  - Line Segment,
  - Arrow,
  - Triangle / Cone,
  - Streamlet,
  - etc.
- Each glyph encodes orientation, and often magnitude and direction
  - Sometimes are drawn curved

Glyphs



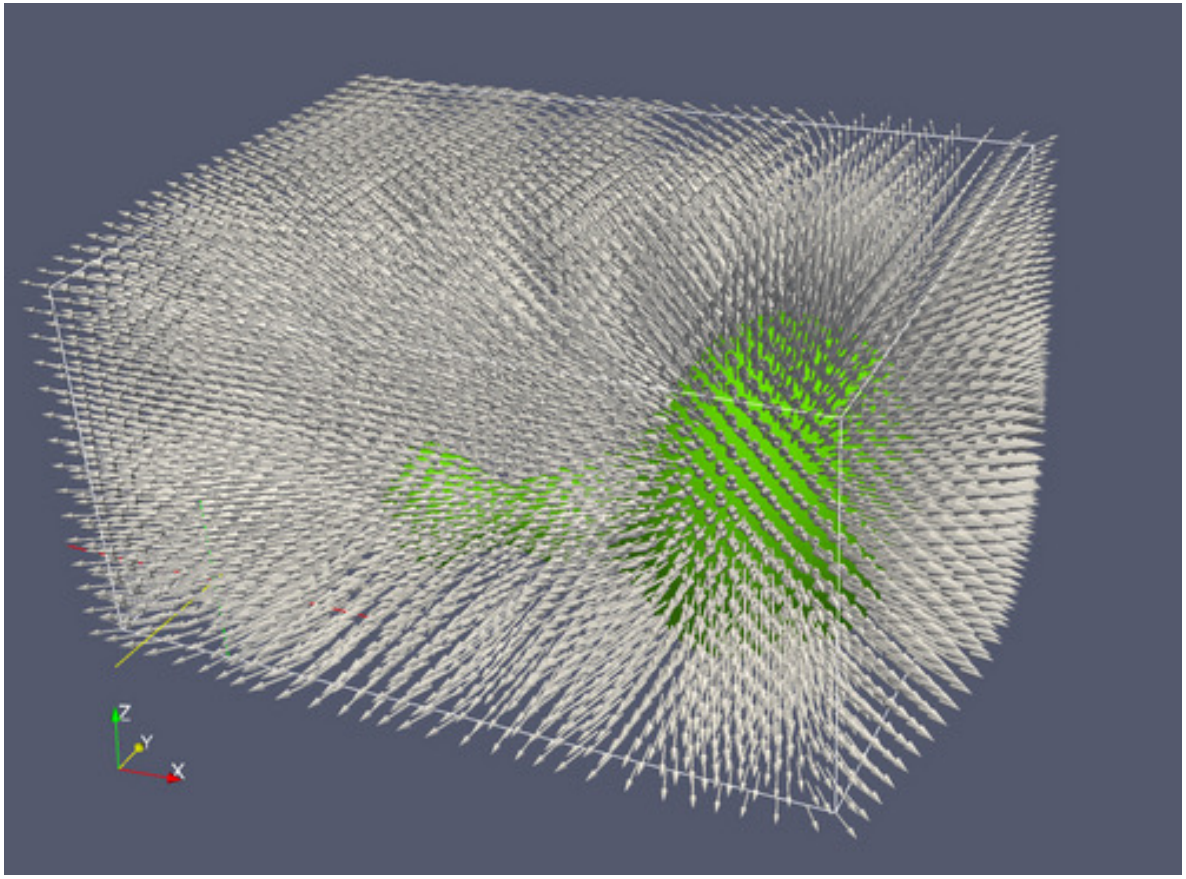
From:
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.cs.rug.nl%2Fsvcg%2FDataVisualizationBook%2FSc6&psig=AOvVaw2-yW_BxObVkukvPJVJOnZT&ust=1698825580917000&source=images&cd=vfe&opi=89978449&ved=0CBEQjhxqFwoTCJiT1NHon4IDFQAAAAAdAAAAABAD

Glyphs

- Can also use color, shape, pattern of glyphs to encode information
- Glyphs cannot be interpolated the same way as color/scalar fields
- Research has identified much more complex glyphs, that encode more information
  - Less intuitive, but can provide more information

3D Glyph Visualization

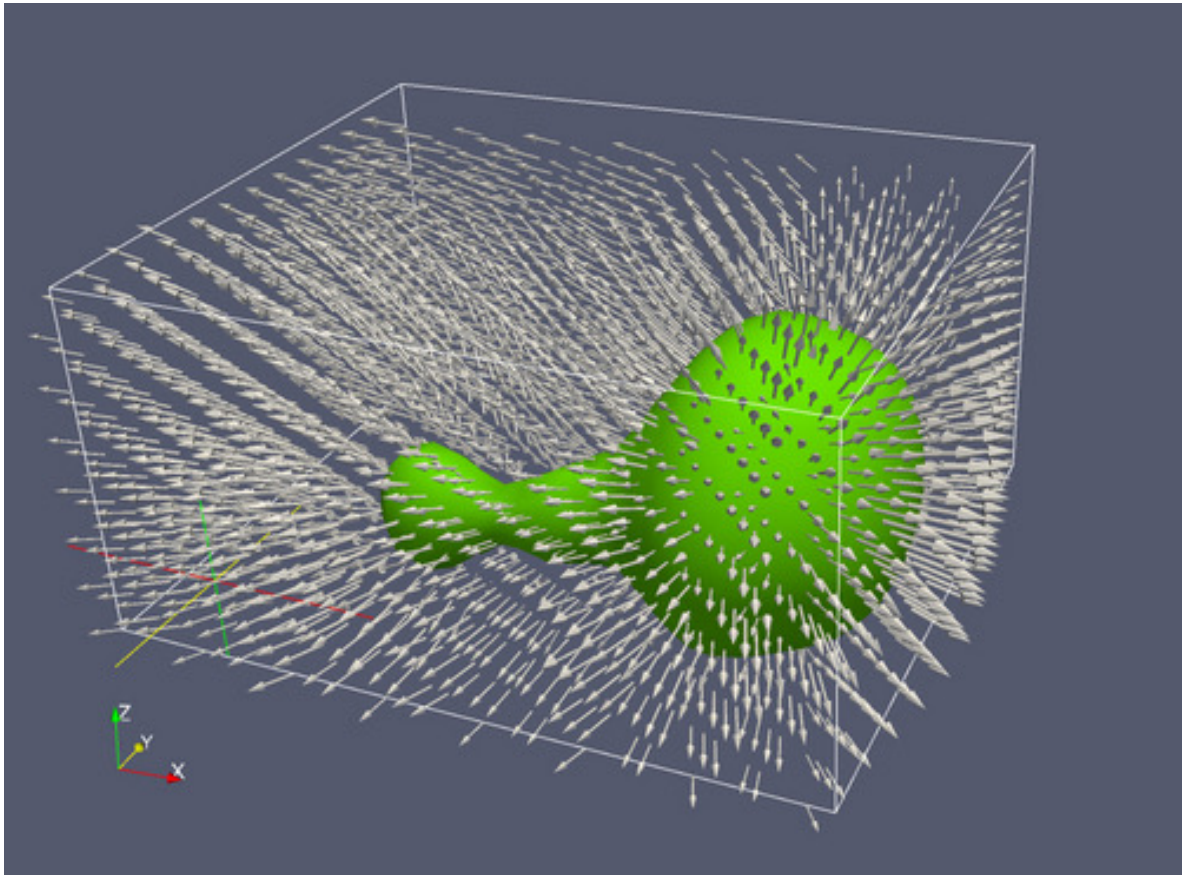
- Arrow glyphs on grid (very dense)



From:
https://www.bu.edu/tech/support/research/training-consulting/online-tutorials/introduction-to-scientific-visualization-tutorial/techniques/hedgehog-glyphs/

3D Glyph Visualization

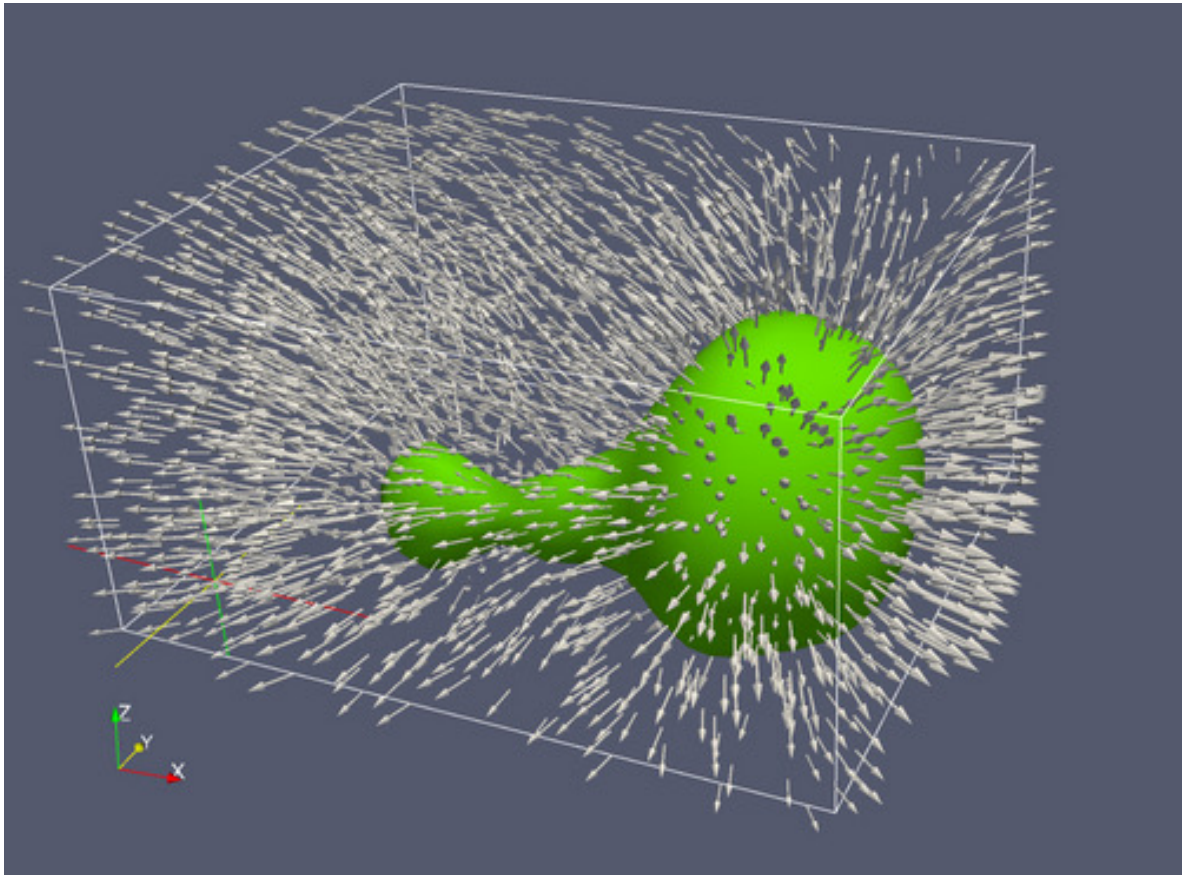
- Reducing clutter by sparser representation



From:
https://www.bu.edu/tech/support/research/training-consulting/online-tutorials/introduction-to-scientific-visualization-tutorial/techniques/hedgehog-glyphs/

3D Glyph Visualization

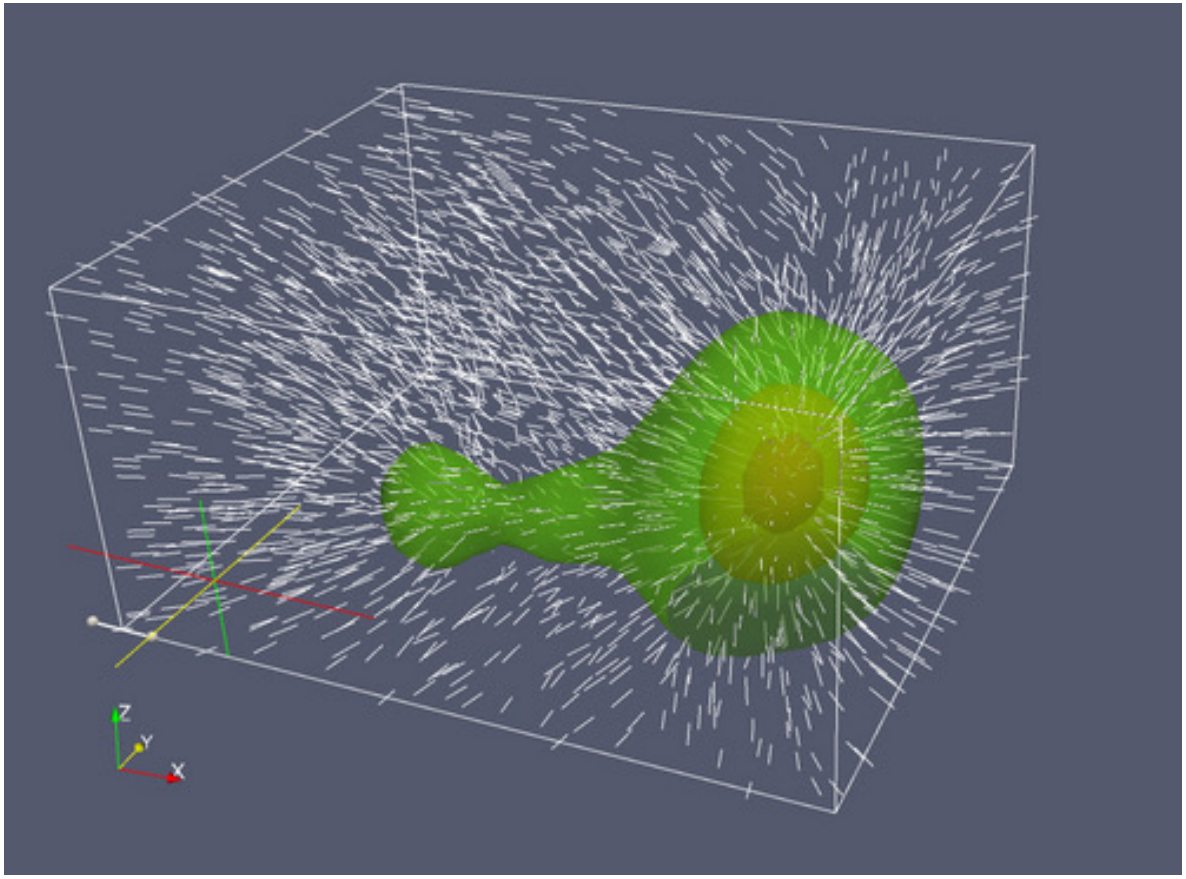
- Random placement of glyphs breaks up patterns



From:
https://www.bu.edu/tech/support/research/training-consulting/online-tutorials/introduction-to-scientific-visualization-tutorial/techniques/hedgehog-glyphs/

3D Glyph Visualization

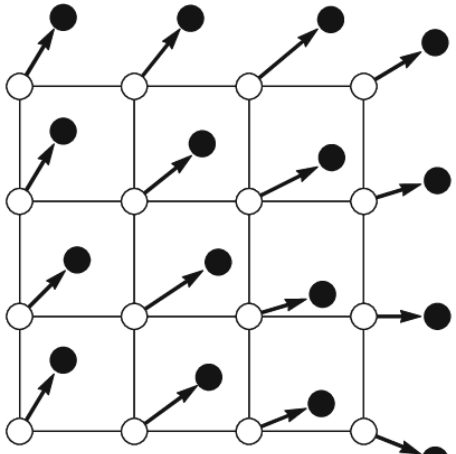
- Drawing with line segment glyphs instead

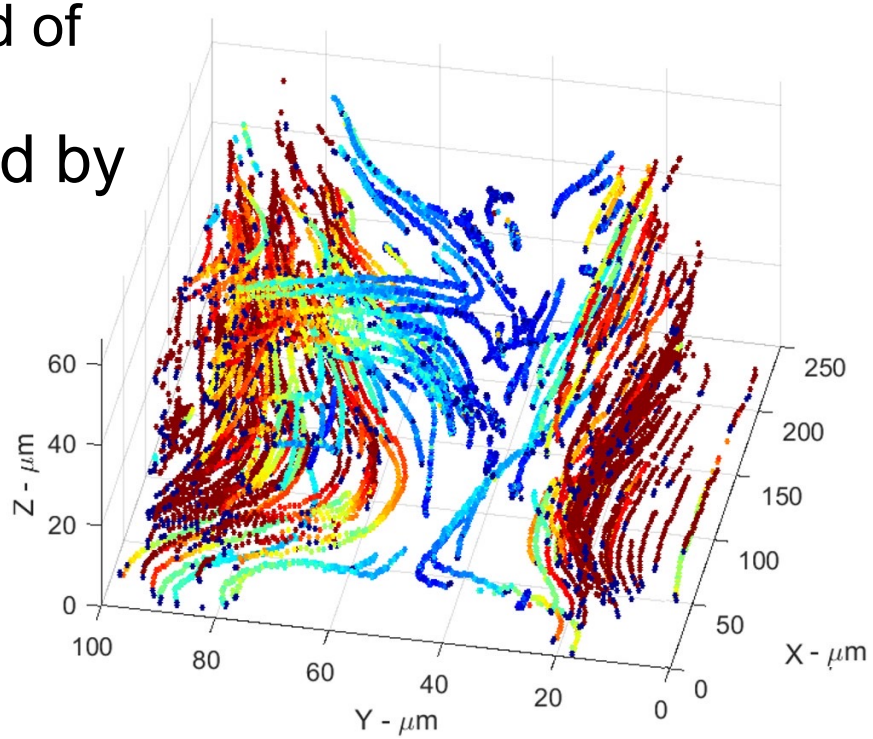


From:
https://www.bu.edu/tech/support/research/training-consulting/online-tutorials/introduction-to-scientific-visualization-tutorial/techniques/hedgehog-glyphs/

Particle Advection

- Place particles into vector field
- Trace path they would follow through the field
  - Simulate for a fixed period of time
- Visualize the path followed by the particle





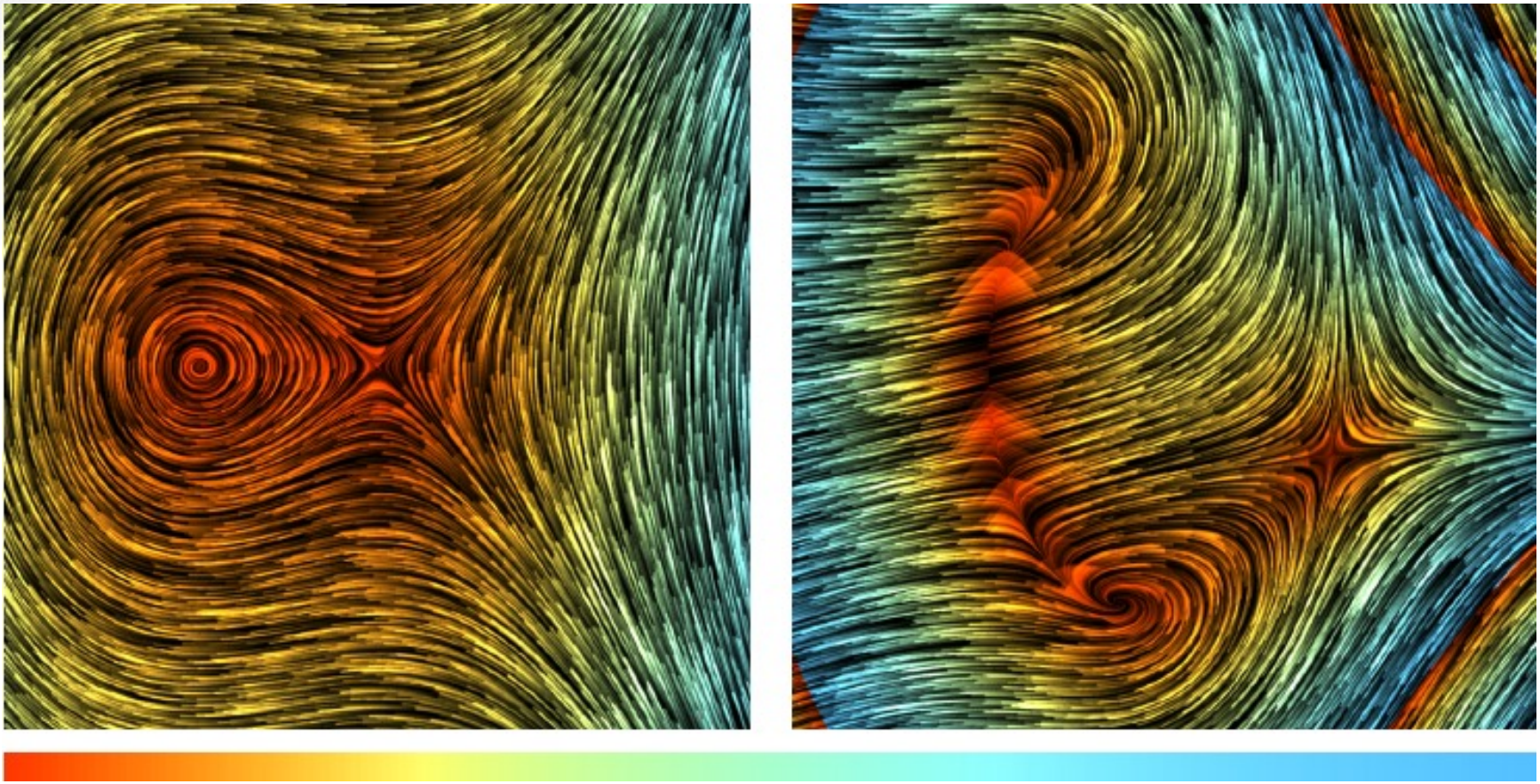
From: https://www.researchgate.net/figure/Particle-advection-where-particles-are-moved-from-their-initial-location-white-to_fig1_262987292
https://www.nist.gov/image/fluids-suspensions-emulsions-project

Line Integral Convolution

- Creates a smooth image of flow orientation
  - Usually not direction, magnitude
- Convolving a noise function with the stream direction over the whole vector field
  - Convolution: Take one function (kernel) and place at values of another function, then add up
- Depending on size of convolution kernel and exact noise function, different results will be obtained
  - Size determines scale of flow lines shown

Line Interval Convolution

- This example: direction and color = magnitude

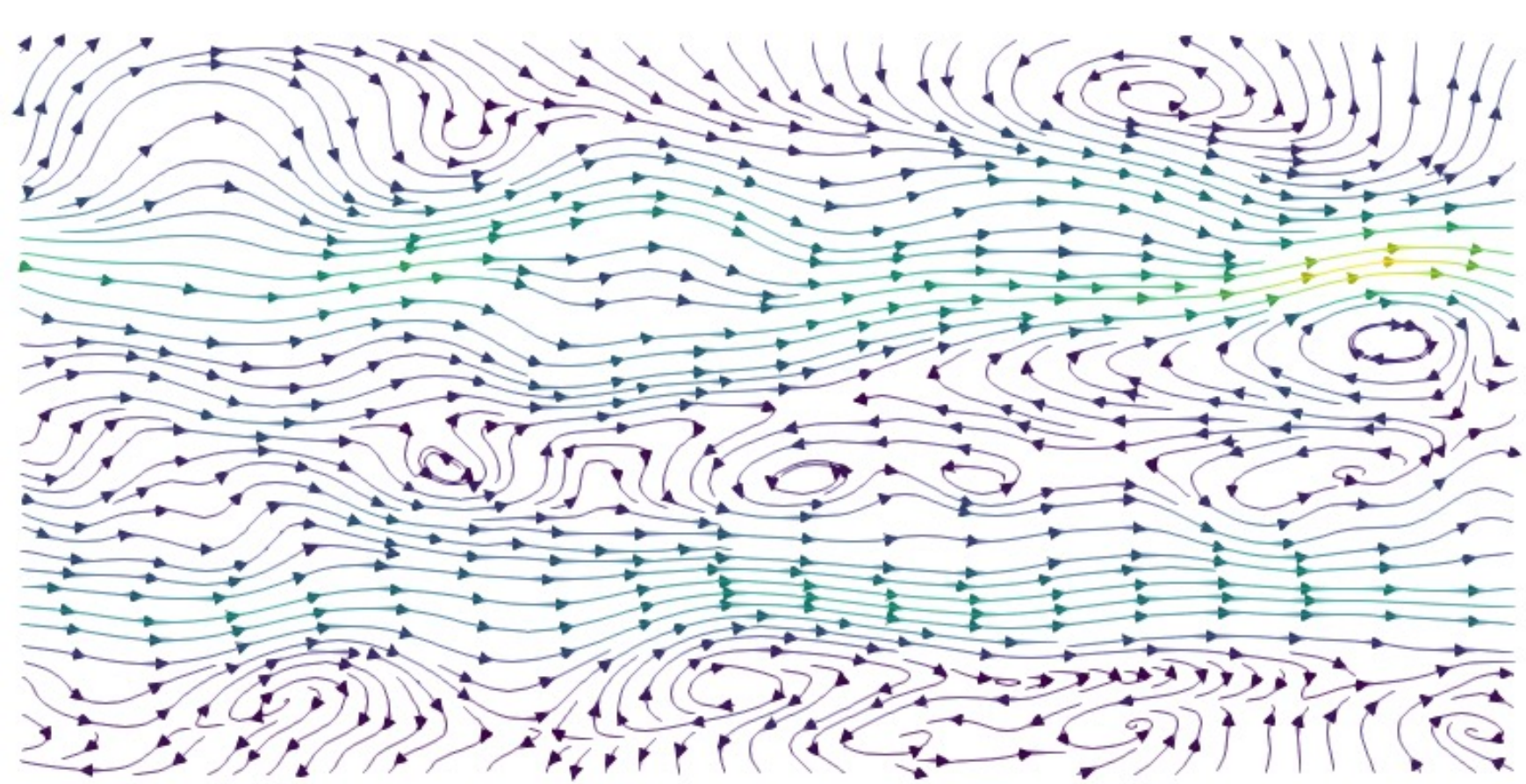


From: https://arxiv.org/pdf/1503.07137.pdf

Streamlines

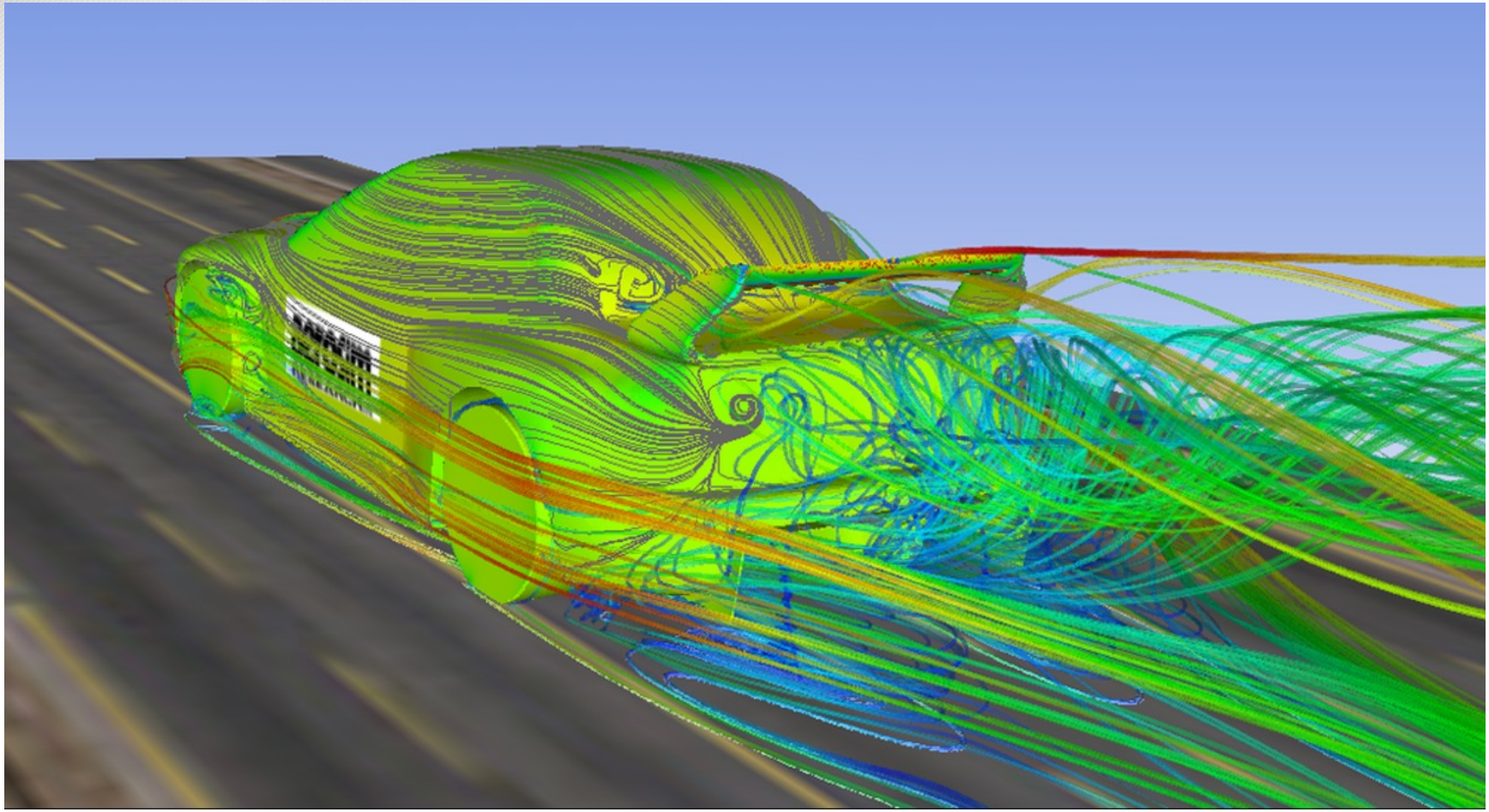
- Streamlines are curves that would give the vector field we have
  - Can be defined as solution of a differential equation that can be integrated to solve for the streamline
- Do not show magnitude (typically); sometimes show direction
- Stream tube is generalization (with width showing amount)

Streamlines



From: https://www.kitware.com/evenly-spaced-streamlines-2d/

Streamlines in 3D

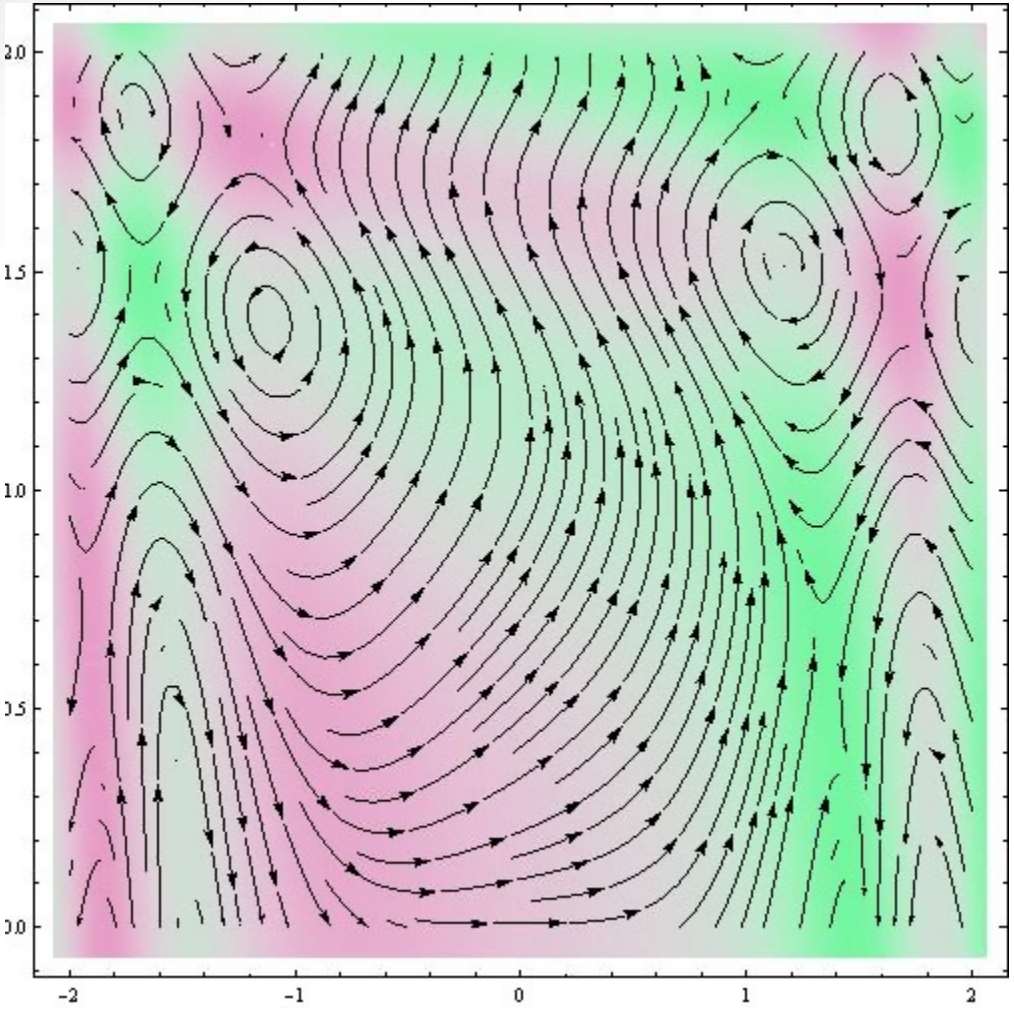


From: https://github.com/ladybug-tools/butterfly/issues/276

Other Approaches

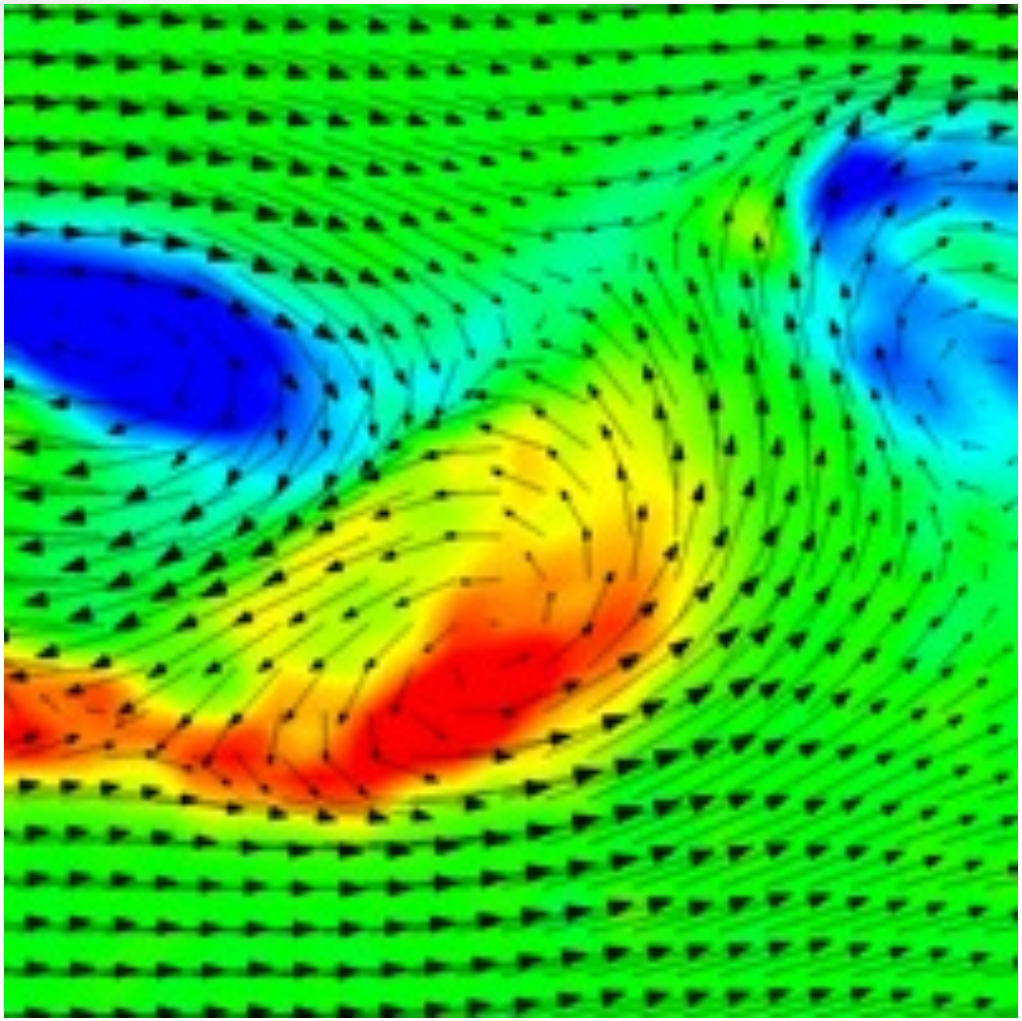
- Can map vector properties to scalars
  - Magnitude of the vector is a scalar
    - Can be mapped, e.g. with color
  - Orientation is a single scalar value
    - Could also be mapped with
    - But, less obvious mapping, since it is cyclic
    - Direction can be incorporated here
- Note: can also map other properties of vector fields
  - Divergence
  - Vorticity

Example: Visualizing Divergence



From:
https://www.wolfram.com/mathematica/newin7/content/VectorAndFieldVisualization/ShowTheDivergenceAsABackgroundDensity.html

Example: Visualizing Vorticity



From: https://tsi.com/discover-tsi/events/seminars/piv-course-application-of-particle-image-velocimetry-theory-and-practice/

References

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- https://www.cs.auckland.ac.nz/compsci716s2t/lectures/716Handout6_VectorIcons_4up.pdf
- https://courses.engr.illinois.edu/cs519/fa2017/Lecture%206%20-%20Vector%20Field%20Visualization%20I.pdf