Comp/Phys/APSc 715

Vector Fields: Particle Systems, Streamlines, Streaklines, Rakes, Ribbons, Glyphs, Textures, Color

Example Videos

- Bdvis: Hentsche Vis 2008
- Paper_1038_movie: Johnson Vis 2008
- Vis2008: Mayerich Vis 2008

Administrative

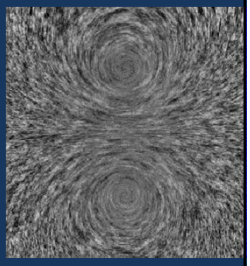
- Homework Grading:
  - Remember to put the PNG files into Zip
  - Remember to put final design image into Zip
- Homework Schedule:
  - Homework 2 deadline moved to Thursday
  - Homework 3 will be done in class Tuesday
  - Homework 4 in the making

Vector/Flow Visualization Goals

- See movement of fluid in an instant or over time
  - Steady state
    - flow field static over visualization
  - Unsteady state
    - flow field changes over time
- Application areas
  - Aerodynamics, CAD, airflow through/around buildings, ocean currents, fluid flow through pumps/valves, electromagnetics

Example Vector Fields

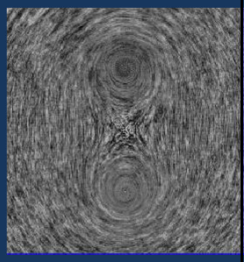
- From Rex Abert at FSU
- Flow with two centers, rotating in opposite directions. Between the centers, the flow is to the right.



http://www.csit.fsu.edu/~rabert/vfresearch/images.html

Example Vector Fields

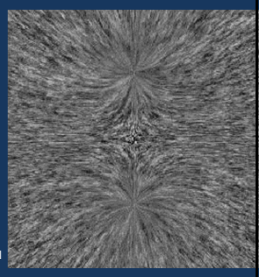
- From Rex Abert at FSU
- Flow with two centers, rotating in the same direction. This produces a saddle point between the two centers. Flow around the centers is counter-clockwise.



http://www.csit.fsu.edu/~rabert/vfresearch/images.html

Example Vector Fields

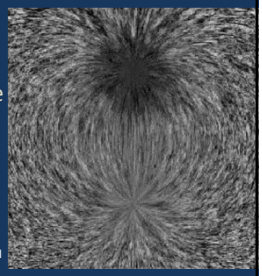
- From Rex Abert at FSU
- Flow with two sinks, producing a saddle between.



http://www.csit.fsu.edu/~rabert/vfresearch/images.html

Example Vector Fields

- From Rex Abert at FSU
- Flow with a source and a sink, producing no saddle between.



http://www.csit.fsu.edu/~rabert/vfresearch/images.html

Vector Visualization Questions (Write these on board)

- Where are critical points in a flow field?
  - Sources, sinks
  - Centers of rotation, Vortices (tornadoes)
  - Fastest flow, stationary (saddle) points
- What is the shape of a flow field?
  - Where is a flow laminar, where is it turbulent?
  - Where is there rotation in a flow?
- Where will an object released into a field end up?
- Where did a concentration (e.g. CO) come from?
- Where does stress cause strain on an object?

Vector Visualization Techniques

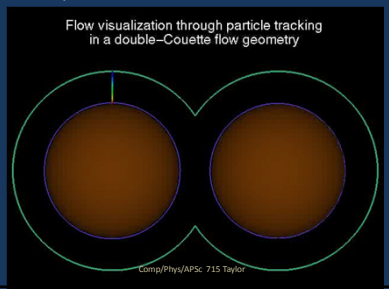
- Advected particles and their trails
  - Particle systems
  - Streamlines
    - Streaklines
    - Rakes
- Glyphs
  - Arrows, tufts, etc.
- Textures
  - Line-integral convolution, Dye advection
- Surfaces
  - Stream Surfaces, Streak Surfaces
  - Deformation of geometric shapes
- Color

Particle Systems

- "Smoke puffs" released into the field
  - Massless particles "go with the flow"
  - Displayed through animation
- Advection method
  - In single time step vs. over multiple time steps
- Release pattern
  - Sphere, flat spray, line, grid, etc.
  - One-time, continuous, bursts

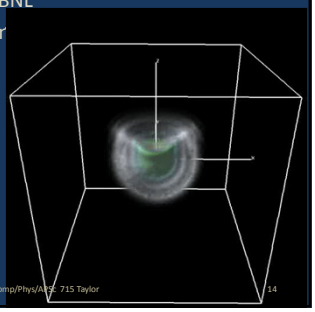
Particle Systems Example 2

- Mickail Teverovskiy and Ica Manas-Zloczower,Case Western Reserve University



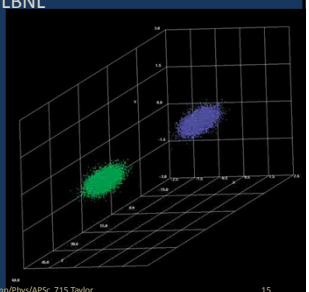
Particle Systems Example 3

- http://www-vis.lbl.gov/Vignettes/
- P.Nugent, D.Kasen, LBNL
- Supernova simulation



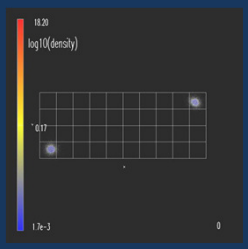
Particle Systems Example 4

- http://www-vis.lbl.gov/Vignettes/
- R. Ryne and J. Qiang, LBNL
- Simulation



Particle Systems Example 5

- http://www-vis.lbl.gov/Vignettes/
- J. Primack, Thomas Cox, UCSC
- Simulation



Particle Characteristics

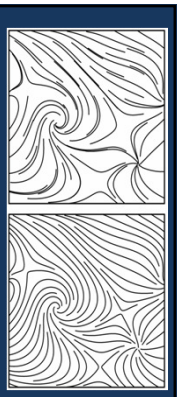
- Benefits
  - Show advection directly
  - Cluster motion shows critical points and features of the flow
  - Motion shows where particles end up
- Difficulties and Issues
  - Occlusion and confusion with lots of particles
  - Hard to remember where particles came from
    - Run in reverse!
  - Placement and timing of release

Streamlines and Their Kin

- "Streaks" left by particle traces, simulations of smoke trails in wind-tunnel experiments
- Geometry
  - Lines, illuminated lines, tubes, ribbons
- Advection method
  - Single time: Called streamlines
  - Over time: Called *streaklines* (look the same)
- Release pattern
  - Single, rakes, grids, etc.

Streamlines

- Turk and Banks
- SIGGRAPH 1996
- Placement and spacing matters

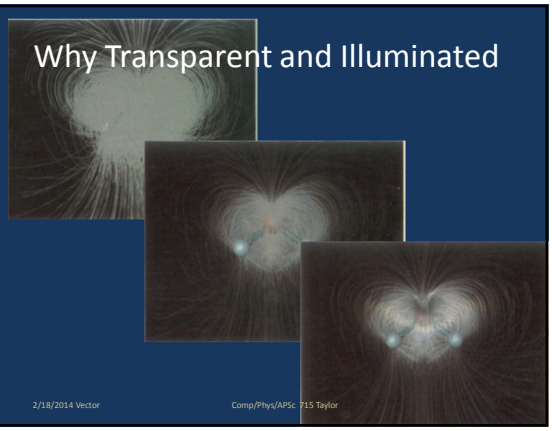


Streamline Examples

- Anna Turnage, IEEE CG&A Vol 2 No 3, 2002. Pp. 16-21

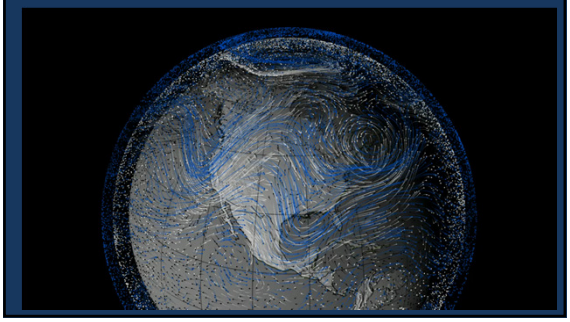
Illuminated Translucent Streamlines

Why Transparent and Illuminated



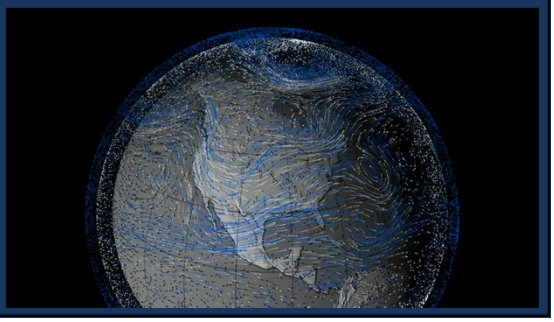
Short Streamlines (1)

http://earthobservatory.nasa.gov



Short Streamlines (2)

http://earthobservatory.nasa.gov



Tubes

- Tube = surface at constant distance from streamline
- 3D entities for improved perception
- Auxiliary information display
  - can color to show value
  - can vary radius to show value

Tubes Example

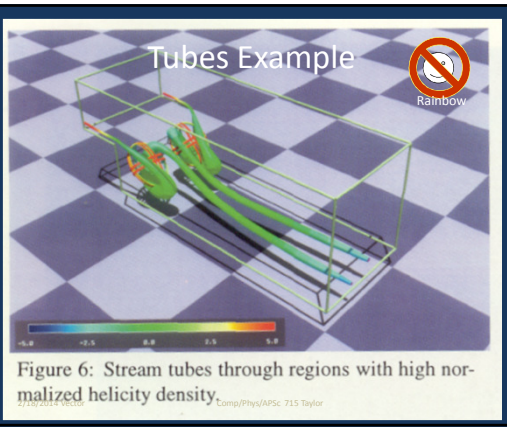
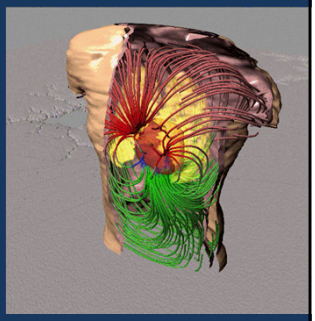


Figure 6: Stream tubes through regions with high normalized helicity density.

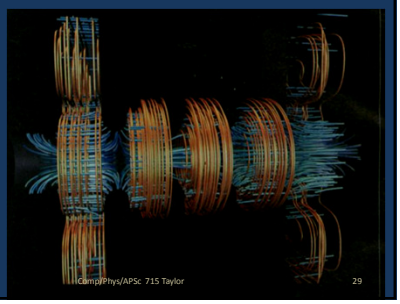
Tubes Example 2

- C.R. Johnson, R.S. Macleod, and M. Matheson, Univ. of Utah
- Electric Current in Thorax
  - Colored by polarity



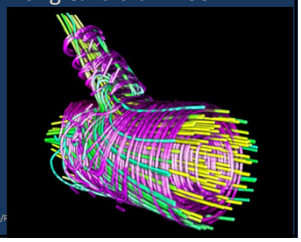
Tubes Example 3

- Greg Schussman and Kwan-Liu Ma, 2002
  - UC Davis
- Electric field
  - Blue
- Magnetic
  - Orange
- Simulation
  - Accelerator



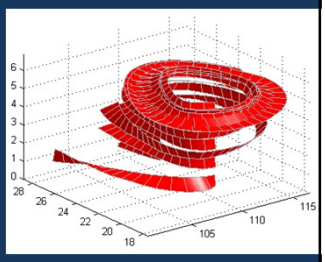
Tubes Example 4

- Interactive volume rendering of thin thread structures within multivalued scientific data sets: Wenger, Keefe, Zhang & Laidlaw 2004
- Velocity (Ylw,Grn)
- Vorticity (Ppl,Pnk)
- Halos
- Volume Rendered

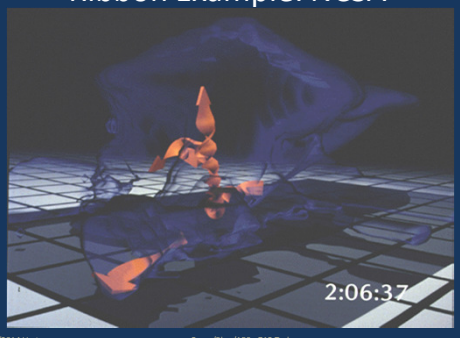


Ribbons

- Advected line plus twist of the line
- Matlab example:
- Reveals twist

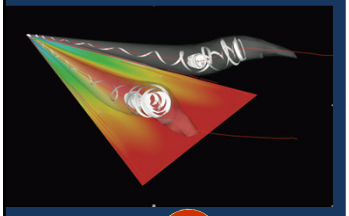


Ribbon Example: NCSA



Ribbon Examples

- Anna Turnage, IEEE CG&A Vol 2 No 3, 2002. Pp. 16-21

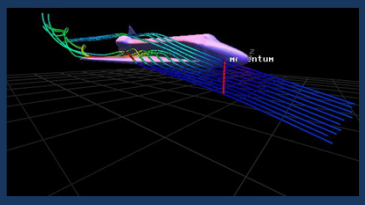


7 Helicopter rotor blades colored according to pressure, with portions of the wake and vortices shown from a vortex lattice core. (Image by Chris Szymendera, Lyle N. Long, and Kent Misegades.)

Rainbow

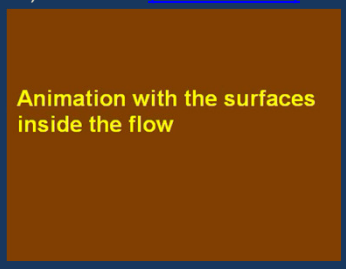
1D Rake

- NASA Ames Virtual Wind Tunnel
- Lines seeded uniformly along a line



Streamlines and other effects

- Vis 2004, Xue et. al. (Link to movie)



Streamline Characteristics

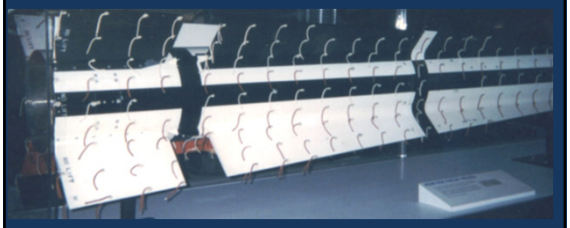
- Benefits
  - Show advection directly
  - Cluster motion shows critical points and features of the flow
  - Shows where flows go, and where they came from
  - Can show twist (with ribbons) as well as advection
- Difficulties and Issues
  - Occlusion and confusion with lots of lines
  - Which direction is the flow?
  - Placement of release
    - show off interesting features
    - even spacing in merging/diverging fields

Glyphs

- Placing individual icons scattered in the field
  - Features of icons reveal information about the field
- Some techniques
  - Arrows / hedgehog / tufts
  - Tensor glyphs (flow probes)

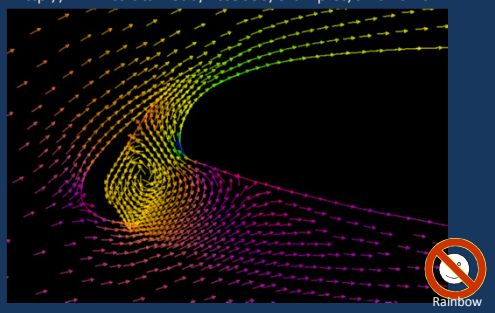
The Real Thing

- U.S. Air and Space Museum near Dulles



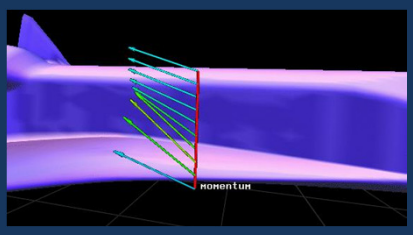
Arrows

- http://www.cs.utah.edu/~cs5630/examples/arrows.html



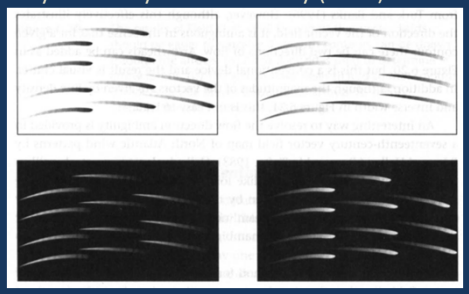
Arrows Along a Rake

- NASA Ames Virtual Wind Tunnel

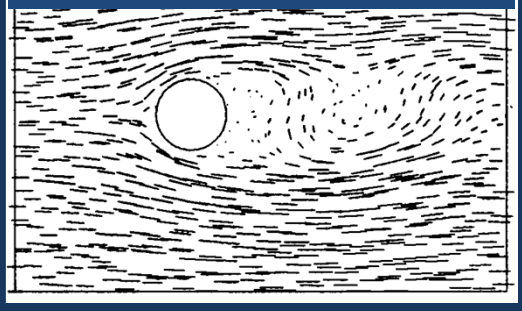


Tufts

- Style used by Edmund Halley (1696)

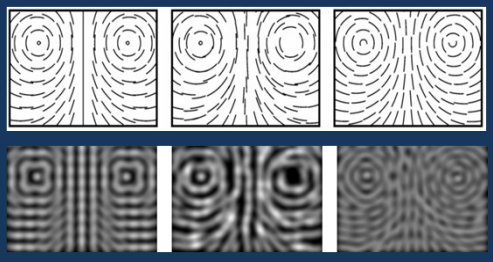


Straight-line Glyphs

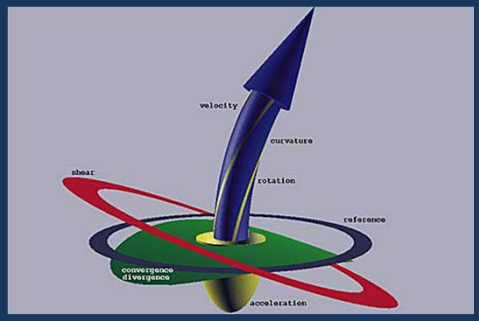


Curved-line Glyphs

- Turk and Banks, SIGGRAPH 1996



Flow Probe



Tubes and Flow Probes

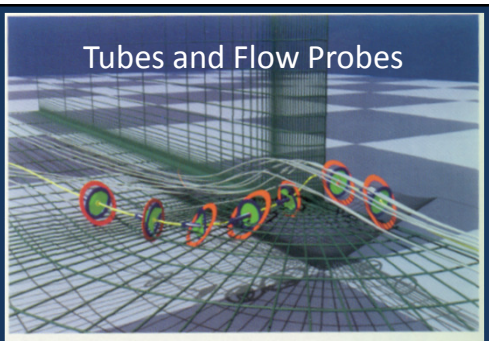
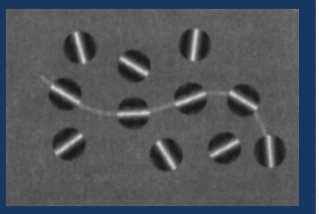
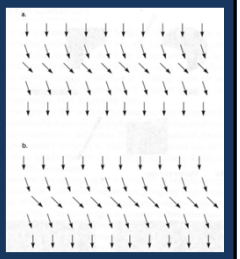


Figure 8: Flow probes along a streamline in a blunt fin dataset.

Arrow Placement

- Ware: Aligned head-to-tail perceived as flow



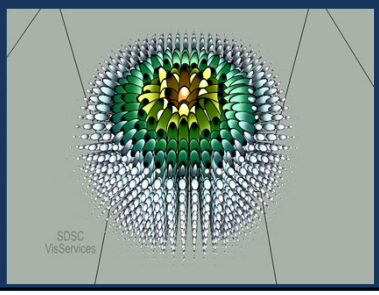


Arrow Placement 2

- Turk and Banks, SIGGRAPH 1996

GlyphSea

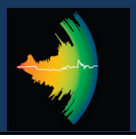
- Amit Chourasia, et. al., SDSC

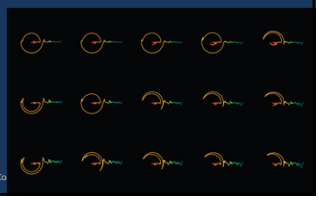


Flow RADAR Glyphs

- Hlawatsch, Leub, Nowal, Weiskopf; TVCG 2011
  - Summarizes flow direction over time
  - Beginning of time is at the center (less accurate)
    - Can invert if flow at start matters more
  - Color shows speed
  - Uncertainty range

Use for spatial summary?





Glyph Characteristics

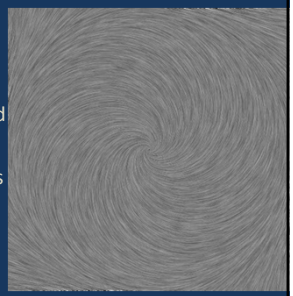
- Benefits
  - Show complicated structure at each glyph location
- Difficulties and Issues
  - Difficult to use densely in 3D (due to occlusion)
    - Consider modulating presence based on scalar field
  - Size (smaller sampling vs. larger to show more info)
  - Placement
    - Regular vs. flow-following
    - Analysis of topology
    - Interactive probing

Textures

- Construct a texture that shows the field
- Techniques
  - Line-Integral Convolution (LIC)
  - Spot Noise
  - Reaction-Diffusion
  - Dye Advection
- Additions
  - Animation
  - 3D volume (doesn't work as well, but halos help a lot)

2D Animated LIC Example

- From H.W. Shen, Univ. of Utah
- 2D line-integral convolution visualization of a vector field
- http://www.cs.utah.edu/~cs5630/examples/lic.html
- (Video – click on it)
- Link



Oriented "LIC" (spot noise)

- Flow direction indicated by anisotropic splats

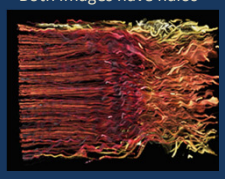
Rainer Wegenkittl and Eduard Groller, 1997

3D LIC with and without Halos

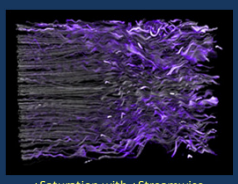
- http://www-users.cs.umn.edu/~interran
- Victoria Interrante, Visualization 1997
- Link

3D LIC plus color (1)

- Victoria Interrante
- Both images have halos



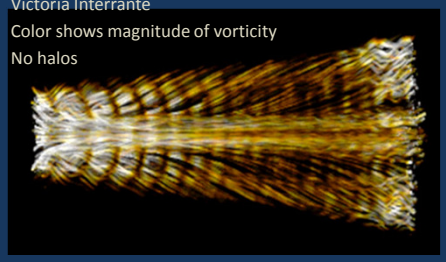
Color from red to yellow with +Temp



+Saturation with +Streamwise vorticity

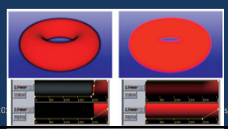
3D LIC plus color (2)

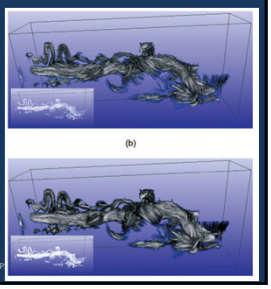
- http://www-users.cs.umn.edu/~interran/3Dflow.html
- Victoria Interrante
- Color shows magnitude of vorticity
- No halos



3D Seed LIC (volume rendered)

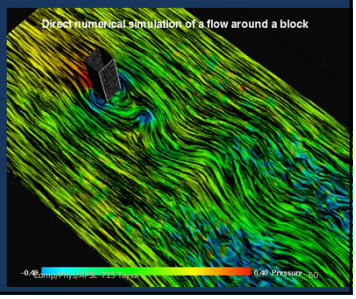
- Helgeland & Andreassen TVCG 2004.
  - Input textures in white
    - ROI from vorticity mag.
  - Top: 9528 seeds
  - Bottom: 20,724 seeds
  - "Limb darkening"





2D Spot Noise

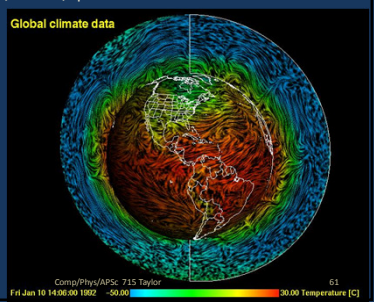
- http://www.cwi.nl/~wimc/spotnoise.html
- Wim de Leeuw



Rainbow

2D Spot Noise on Slices

- http://www.cwi.nl/~wimc/spotnoise.html
- Wim de Leeuw
- 2D LIC in 3D
  - On sphere
  - On slice



Reaction-Diffusion

- Vis 2004: Sanderson, Johnson, Kirby
  - Adjusting reaction rate changes size
  - Anisotropic diffusion causes stretching
  - Touch up
    - Light→dark
    - Direction

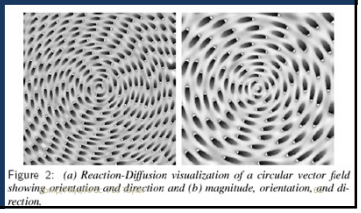


Figure 2: *(a) Reaction-Diffusion visualization of a circular vector field showing orientation and direction and (b) magnitude, orientation, and direction.*

2004 Sanderson, Johnson, Kirby

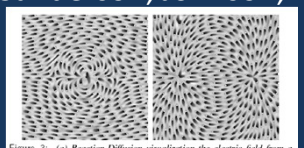


Figure 3: *(a) Reaction-Diffusion visualization the electric field from a dipole and (b) an electrostatic charge.*

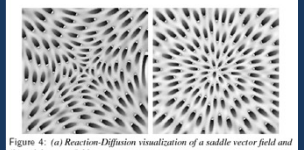


Figure 4: *(a) Reaction-Diffusion visualization of a saddle vector field and (b) a sink vector field.*

2004 Sanderson, Johnson, Kirby

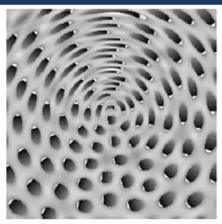


Figure 7: *Reaction-Diffusion visualization of orientation uncertainty. The orientation uncertainty is a function of the angular position.*

2004 Sanderson, Johnson, Kirby

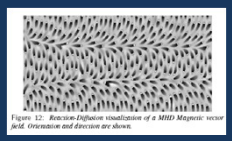


Figure 12: *Reaction-Diffusion visualization of a MHD Magnetic vector field. Orientation and direction are shown.*

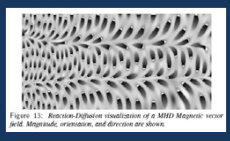


Figure 13: *Reaction-Diffusion visualization of a MHD Magnetic vector field. Magnitude, orientation, and direction are shown.*

Figure 17: *Randomly placed ellipse image of the vector field used in Figure (11).*

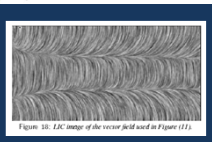
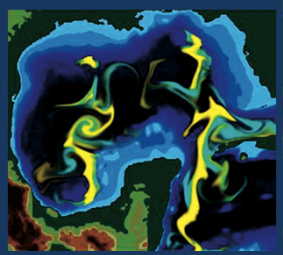
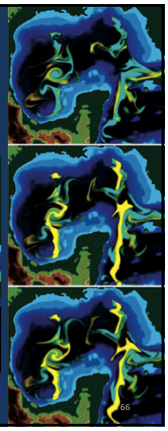


Figure 18: *LIC image of the vector field used in Figure (11).*

Dye Advection

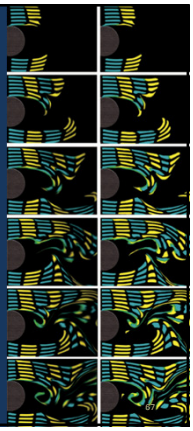
- Sea Currents
  - Gulf of Mexico
- Jobard et al., IEEE Trans V&CG, 8(3)





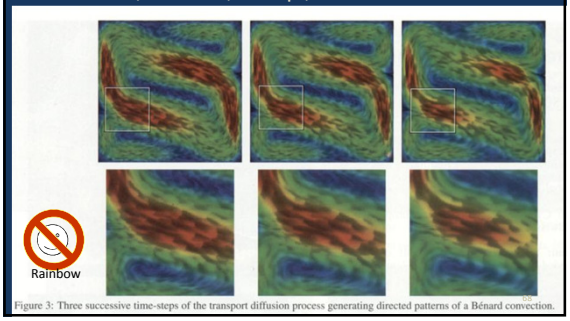
Dye Advection 2

- Flow around a circular cylinder
- Jobard et al., IEEE Trans V&CG, 8(3)



Transport and Anisotropic Diffusion

- Burkle, Preuber, Rumpf, Vis 2001.



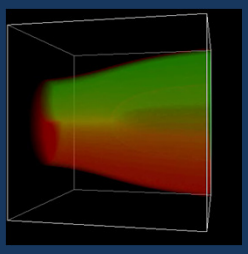
Rainbow

Figure 3: Three successive time-steps of the transport diffusion process generating directed patterns of a Bénard convection.

Complete Texture System

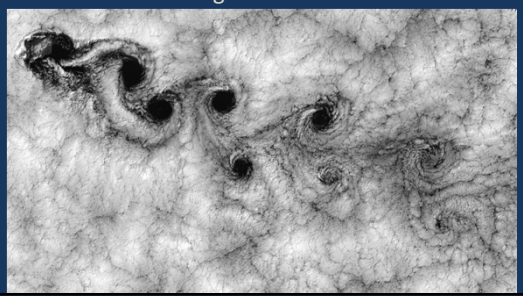
3D Texture System

- Vis 2004, Xue et. al. (Link to video)



The Real Thing

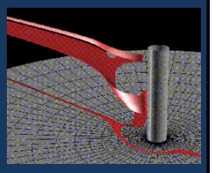
- NASA Landsat image off Chilean coast



Texture Characteristics

- Benefits
  - Shows entire field (at least in 2D)
  - Can animate entire field
  - Shows critical points
- Difficulties and Issues
  - Hard to show in 3D, due to occlusion
  - Hard to get quantitative information

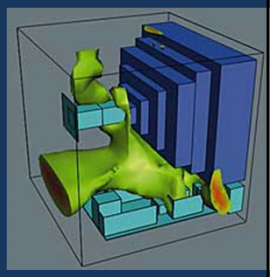
Stream Surfaces



- "Thick" lines within plane or surfaces within volume that show results of flow
- Stream surfaces show outline of region where an initial line (in 2D) or polygon (in 3D) is swept in flow

Stream Surfaces

- Surface swept by patch
- Implementation 1:
  - generate stream lines
  - join adjacent streamlines to form triangles
  - Issue: diverging and merging flows
- Implementation 2:
  - Inject "ink" patch at boundary
  - Advect the ink through field
  - Generate ink isosurface

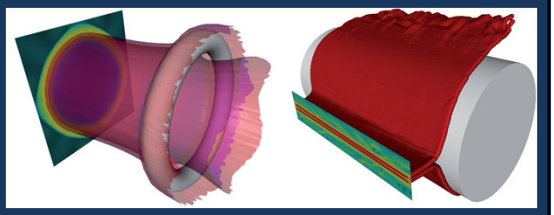


Stream Surfaces

- Helman and Hesselink, Stanford University

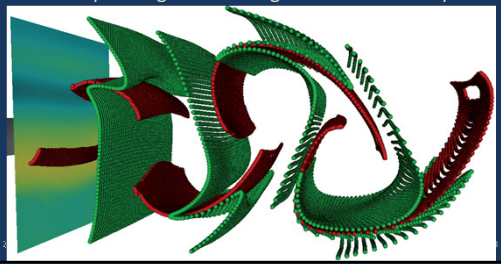
Separating Streak Surfaces (1)

- Ferstl, Burger, Theisel, Westermann; TVCG 2010
  - Separating surfaces on a torus and cylinder



Separating Streak Surfaces (2)

- Ferstl, Burger, Theisel, Westermann; TVCG 2010
  - Red separating surface vs. green time-release planes



Surface Characteristics

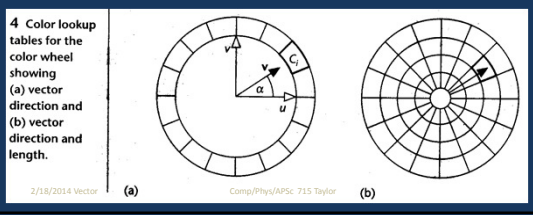
- Benefits
  - Shows where initial concentration ends up
- Difficulties and Issues
  - Show only a subset of the field
  - Significant divergence makes surface large
  - Occlusion can be a problem

Color

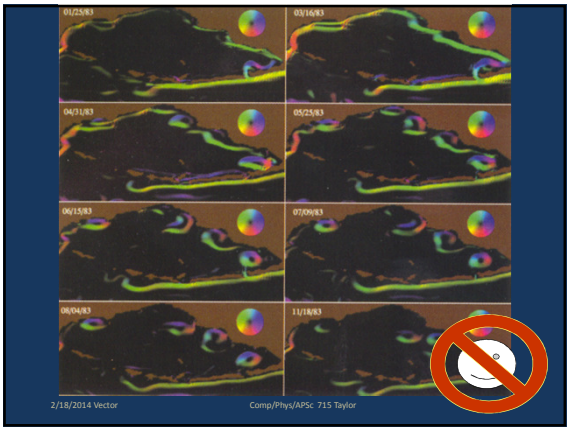
- Color as auxiliary
  - Usually magnitude
  - May be age, release location, or other
- Interactive color
  - Boring and Pang, Vis '96
  - hue to show relationship between vec and light
  - interactive exploration

Color Wheel

- Color wheel
  - Johansen and Moorhead, CG&A '95
  - color angle (hue) shows orientation
  - optionally, magnitude as saturation and/or lightness

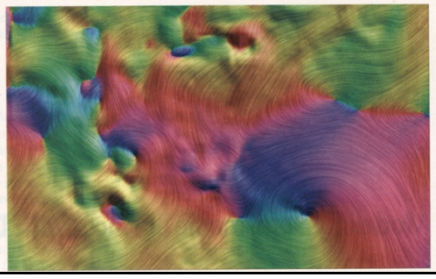


4 Color lookup tables for the color wheel showing (a) vector direction and (b) vector direction and length.



Color to disambiguate direction

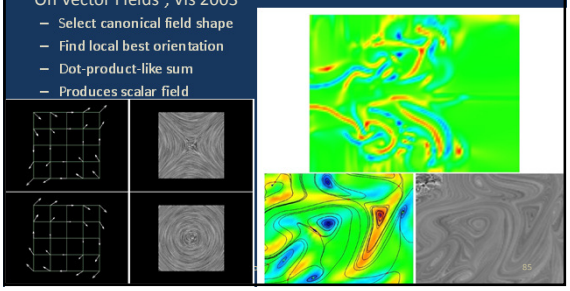
- PNNL: Wong, Foote, Kao, Leung, Thomas



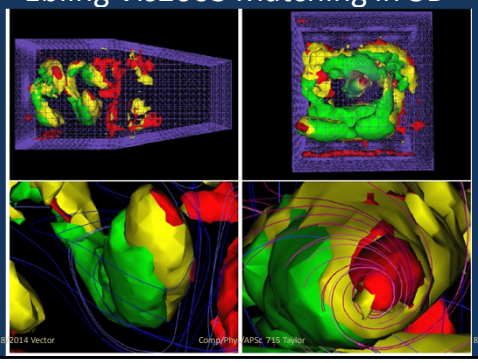
2 The velocity magnitude is used for relief shading, color for direction, and streamlines for structure.

Pattern Matching → Color

- Julia Ebling, "Clifford Convolution And Pattern Matching On Vector Fields", Vis 2003
  - Select canonical field shape
  - Find local best orientation
  - Dot-product-like sum
  - Produces scalar field



Ebling Vis2003 Matching in 3D



Color Characteristics

- Benefits
  - Can show data over the whole field
  - Color good for nominal labeling (release location, age)
  - Color good to overlay scalar data set (magnitude, pressure)
- Difficulties and Issues
  - Mapping direction to color is unnatural
  - Mapping direction + magnitude loses resolution

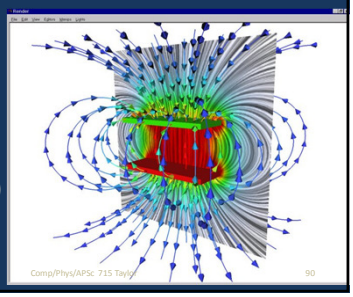
Comparison

- Vis 2004: Laramee: laramee.mpg
  - Different flow visualization techniques
  - http://cs.swan.ac.uk/~csbob/research/swirl-tumble/video/larameeVis04investigating.mpg

Combination of Techniques

Same colors 2 meanings

- Using: Iris Explorer (sold by NAG)
- By: Lutz Justen

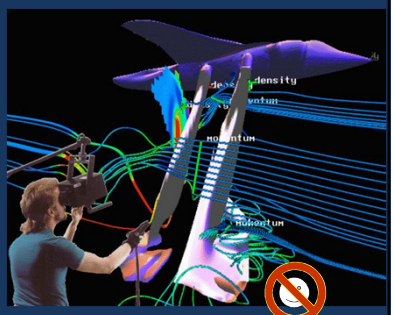


- Streamlines
- Arrow glyphs
  - Show direction
- LIC-like texture
- Color (magnitude)

Combo: Virtual Wind Tunnel

Steve Bryson
NASA Ames

Streamlines
Rakes
Color
Isosurfaces
Cut Plane
Model



Combo: LIC and Velocity Mask

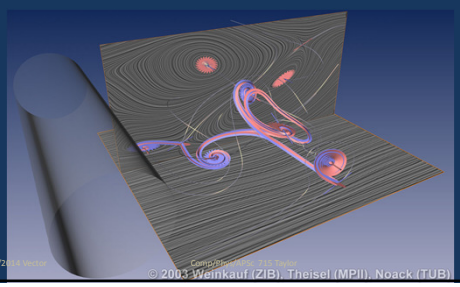
- Sea Currents
  - Gulf of Mexico
- Jobard et. al.
  - IEEE Trans V&CG

Combo: LIC and Velocity Mask

- Cyclone formation
  - Europe
- Jobard et. al.
  - IEEE Trans V&CG

Combo: LIC and Saddle Connectors

- Vis 2003: Theisel, Weinkauf, Hege, Seidel



Summary (2008)

P	S	G	T	Ss	C	Questions
L	Y	Y	G	L/ T	Y	Where are critical points in a flow field?
G	Y	Y	G			What is the shape of a flow field?
L	50	Y	L	50		Where will an object released into a field end up?
T+		T	G	50		Where did a concentration (e.g. CO) come from?

Y = yes, + = really good, L = if you're lucky,
T = with tricks, 50 = directional ambiguity

Summary (2005)

Par	Li	Gl	Tex	Sfc	Clr	
L	L+	Ok	Ok	X	X	Sources and sinks
Ok	Tr	Ok	Ok	X	Ok	Fast/slow/still
Ok	L	Ok	Ok	X	X	Center of rotation
Ok	+	Ok	Ok	X	X	Shape of flow
Ok	++	?	Ok	X	X	Where is flow laminar vs. turbulent?
++	T	L	Dye	L	X	Where would a pushed object end up?
T	T	L	T	L	X	Where does a concentration come from?
Ok	Ok	Ok	?	+	X	Where does stress cause strain?
T	T	Ok	T	T	++	Positive vs. negative field (scalar)?

L=If you're lucky, += Real good, T=With tricks

Summary (from 2003)

P~	L~	G	T2+	S~	C*	Where are sources and sinks?
P	L	G	T2+	S~	C*	Where is flow laminar vs. turbulent?
P~	L~	G~	T2+			Center of rotation
P	La	G+	Ta			Local flow direction
P~		G~	Th		C	Where is flow fastest?
P+	La	G~	T*	S		Where would a pushed object end up?
P*	La	G~	T*	S		Where does a concentration come from?
P	L~	G~	T2+		C*	Where are stationary points?
N		G			C	Positive vs. negative field (scalar)?

Particle, Lines, Glyph (answers for 2D), Texture, Surface, Color
~=If you're lucky, += Real good, *=With tricks, 2=2D, a= ambiguity, h=hard

Summary (from 2002)

P+	L	G+	T2			Where are sources and sinks?
						Where is flow laminar vs. turbulent?
P	L	G	T2+			Where is rotation in flow?
P	L	G				Where is twist in 3D flow?
P	L	G~				Where is vertex core in 3D flow?
P	L+	G	T2+			Where are saddles?
P		G*	T	S~	C	Where is flow fast vs. slow?
P+	L~	G	T2	S~		Where would a pushed object end up?
P	L+	G	T	S+		Where does a concentration come from?
P		G+	T	S		Direction of flow (along a surface)?
P~		g	T			Where are stationary points?
		G			C	Positive vs. negative field (scalar)?

Particle, Lines, Glyph, Texture, Surface, Color
~=If you're lucky, += Real good, *=With tricks, g=small dense glyphs, 2=2D

Credits

- This lecture is based on a lecture given by Penny Rheingans at University of Maryland Baltimore County, for course CMSC 491B/691B.
- Flow Probe: Wijk, J.J. van, A.J.S. Hin, W.C. deLeeuw, F.H. Post, "Three Ways to Show 3D Fluid Flow." IEEE Computer Graphics and Applications, vol. 14, no. 5, p. 33-39, September 1994.
- Stream Surfaces: CJM. Lasance, Philips Research (found on http://www.electronics-cooling.com/html/1999_jan_article3.html).

Credits

- Arrows, Streamline Example: Jean M. Favre, GWU.
- Tufts, Arrow Placement, Colin Ware, "Information Visualization"
- Noise-based advection with velocity mask, Dye advection: Jobard et. al. "Lagrangian-Eulerian Advection of Noise and Dye Textures for Unsteady Flow Visualization," IEEE Trans. Vis. & Comp. Gfx. 8(3), July-Sept 2002.
- Others: As listed on slides.