CSE3020 - Data Visualization

Module 2 :Visualization Techniques

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Topics to be covered

- Scalar Visualization techniques
  - Color Mapping
  - Designing Effective Colormaps
  - Contouring
  - Height Plots
- Vector visualization techniques
  - Introduction
  - Vector Glyphs
  - Vector Color Coding
  - Stream Objects

Scalar Visualization techniques

- **Introduction**
  - Visualizing scalar data is frequently encountered in science, engineering, and medicine, but also in daily life.
  - Scalar datasets, or scalar fields, represent functions $f:D \rightarrow R$, where D is usually a subset of R2 or R3.
  - There exist many scalar visualization techniques, both for 2D and 3D dataset

Scalar Visualization techniques

- **Introduction**
  - Scalar attribute
    - Scalar attributes are $c = 1$ dimensional
    - Scalar has a Magnitude
    - Plain Real Numbers
    - Example : Temperature, Pressure, concentration, geometrical measures (length or height)
  - Scalar functions

$f: R \rightarrow R$
1-D, histogram
$f: R^2 \rightarrow R$
2-D, color mapping, contouring, height plot
$f: R^3 \rightarrow R$
3-D, isosurface, slicing, volume visualization

Source: Data Visualization Principles and Practice , Alexandru C Telea

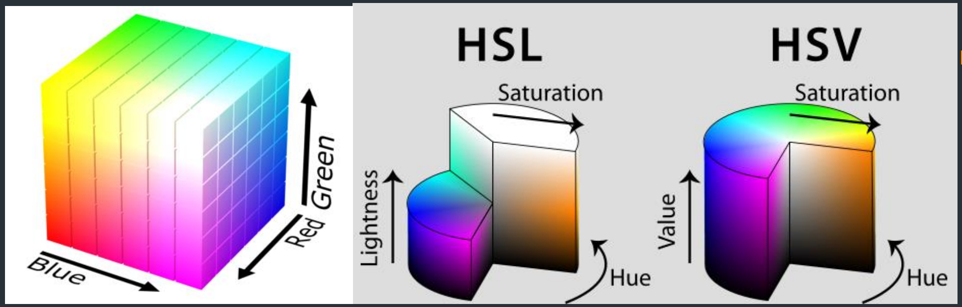
Scalar Visualization techniques

- **Introduction**
  - Vector attribute
    - Vector attributes are $c = 2$ or 3 dimensional
    - Vector has a Magnitude and Direction or Orientation
    - It can encode position, direction, force or gradients of scalar functions.

Scalar Visualization techniques

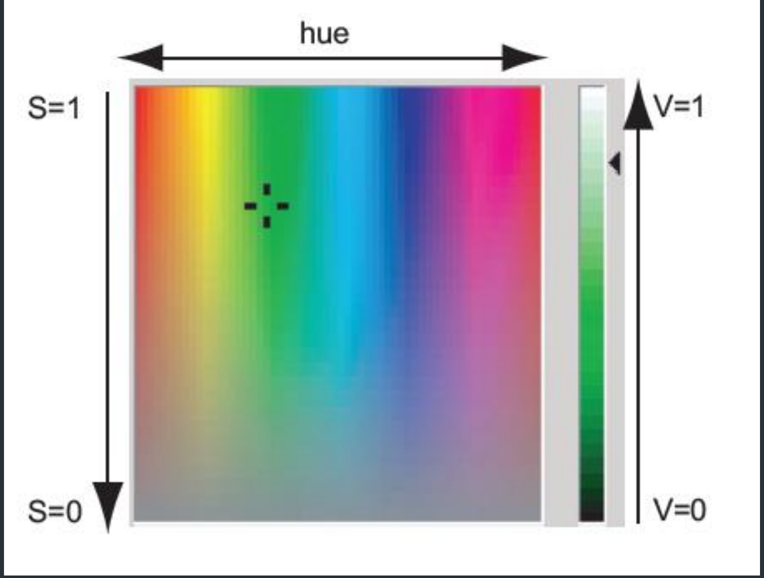
Introduction

- Color attribute
  - Color attributes are c = 3 dimensional and represents the displayable colors
  - three components of a color attribute can have different meanings, depending on the color system in use
  - Color Representation System
    - RGB (Red, Green, Blue)
    - HSV (Hue, Saturation, Value)
    - HSL (Hue, Saturation, Lightness)



Source: Data Visualization Principles and Practice , Alexandru C Telea

Scalar Visualization techniques



Introduction

- RGB (Red, Green, Blue)
  - Additive system, i.e., every color is represented as a mix of “pure” red, green, and blue colors in different amounts
  - Equal values - gray shades
- HSV (Hue, Saturation, Value)
  - it is more intuitive for the human user
  - Hue distinguishes between different colors of different wavelengths, such as red, yellow, and blue
  - Saturation represents the color “purity
  - *Value* represents the brightness or luminance

Source: Data Visualization Principles and Practice , Alexandru C Telea

Scalar Visualization techniques

- **Scalar Visualization Techniques**
  - Color mapping
  - Contouring
  - Height Plots

Scalar Visualization techniques

- **Color Mapping**
  - Color mapping is probably the most widespread visualization method for scalar data.
  - Color mapping associates a color with every scalar value.
  - Mapping function

    $$m : D \rightarrow D_V$$
  - There are several ways to define such a scalar-to-color function.
    - Color look-up tables
    - Color transfer functions

Scalar Visualization techniques

Color Look up Tables

- Color look-up tables are the simplest way to implement color mapping.
- Color mapping function c:

$$C = \{c_i\}_{i=1..N}, \qquad \text{where} \quad c_i = c\left(\frac{(N-i)f_{\min} + i f_{\max}}{N}\right).$$

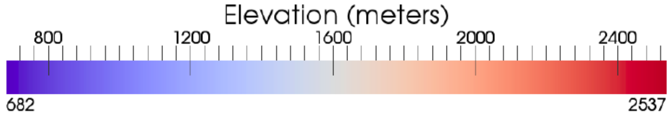
- Simply put, a color look-up table ***C***, also called a colormap, is a uniform sampling of the color-mapping function ***c***:

Scalar Visualization techniques

Color Look up Tables

- Scalar values greater than the maximum are clamped to the maximum color, scalar values less than the minimum are clamped to the minimum value

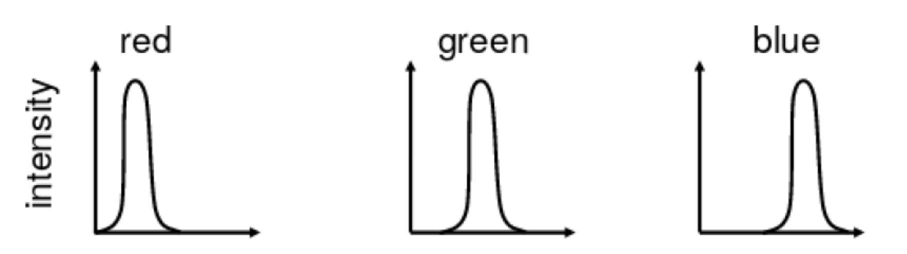
R	G	B	Result
0.0	0.0	0.0	black
1.0	0.0	0.0	red
0.0	1.0	0.0	green
1.0	1.0	0.0	yellow
0.0	0.0	1.0	blue
1.0	0.0	1.0	magenta
0.0	1.0	1.0	cyan
1.0	1.0	1.0	white



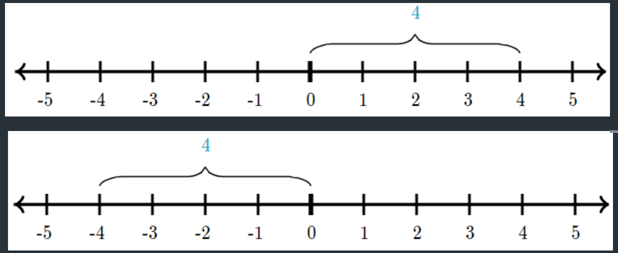
Scalar Visualization techniques

Color Transfer Function

- A transfer function is any expression that maps scalar values into a color specification.
- Ex: a function can be used to map scalar values into separate intensity values for the red, green, and blue components



Scalar Visualization techniques



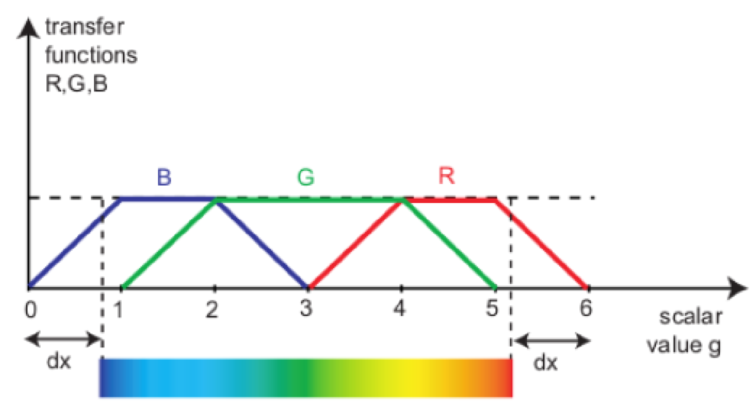
- **Designing Effective Color Maps**
- Different types of analysis goals require different types of colormaps.
  - *Absolute values*: Tell the absolute data values at all points in the displayed dataset.
  - *Value ordering*: Given two points in the displayed dataset, tell which of the corresponding two data values is greater.
  - *Value difference*: Given two points in the displayed dataset, tell what is the difference of data values at these points.

Source: Data Visualization Principles and Practice, Alexandru C Telea

Scalar Visualization techniques

- **Designing Effective Color Maps**
  - *Selected values*: Given a particular data value *f* interest , tell which points in the displayed data take the respective value *f* interest . A variation of this goal replaces *f* interest by a compact interval of data values.
  - *Value change*: Tell the speed of change, or first derivative, of the data values at given points in the displayed dataset

Scalar Visualization techniques



Designing Effective Color Maps

- Rainbow colormap
  - Many engineering and weather forecast applications use a blue-to-red colormap, often called the rainbow colormap.
  - This colormap is based on the intuition that blue, a “cold” color, suggests low values, whereas red, a “hot” color, suggests high values

Scalar Visualization techniques

- **Designing Effective Color Maps**
- Rainbow colormap

```
void c( float f , float& R, float& G, float& B)
{
const float dx = 0 . 8 ;
f = ( f <0)? 0 : ( f >1)? 1 : f ; //clamp f in [0, 1]
g = (6 −2∗ dx ) ∗ f + dx ; // scale f to [dx, 6 − dx]
R = max(0 ,(3 − f a b s ( g−4)− f a b s ( g − 5 ) ) / 2 ) ;
G = max(0 ,(4 − f a b s ( g−2)− f a b s ( g − 4 ) ) / 2 ) ;
B = max(0 ,(3 − f a b s ( g−1)− f a b s ( g − 2 ) ) / 2 ) ;
}
```

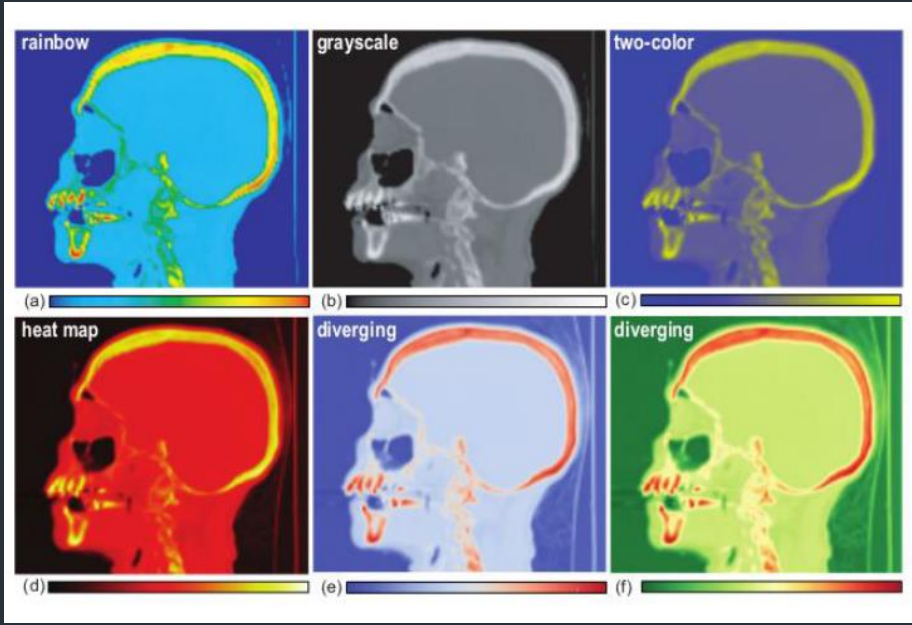
Source: Data Visualization Principles and Practice , Alexandru C Telea

Scalar Visualization techniques

- **Designing Effective Color Maps**
- Rainbow colormap has limitations
  - **Focus:** Perceptually, warm colors arguably attract attention more than cold colors.
  - **Luminances:** of the rainbow colormap entries vary non-monotonically. This leads to users being potentially attracted more to certain colors than to others.
  - **Context:** Hues can have application-dependent semantics.
  - **Ordering:** we cannot assume that any user will order hues in this particular manner

Scalar Visualization techniques

- Other Colormap designs



Source: Data Visualization Principles and Practice , Alexandru C Telea

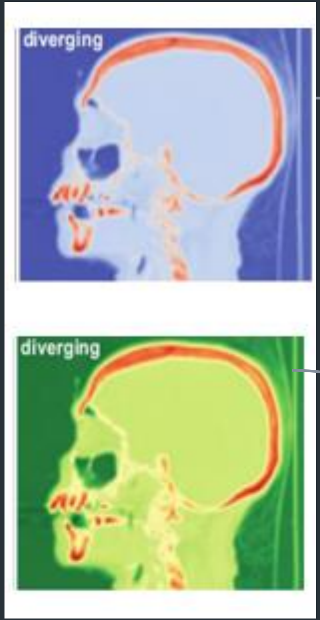
Scalar Visualization techniques

- Other colormap designs
- **Grayscale:**
  - it maps data values ***f*** linearly to luminance, or gray value, with ***f*** min corresponding to black and ***f*** max corresponding to white.
  - Most medical specialists, would agree that the grayscale produces a much easier-to-follow, less-confusing visualization on which details are easier to spot

Scalar Visualization techniques

- Other colormap designs
- **Two-hue:**
  - The two-hue colormap can be seen as a generalization of the grayscale colormap, where we interpolate between two colors, rather than between black and white.
- **Heat Map:**
  - It represents the color of an object heated at increasing temperature values.
    - Black corresponding to low data values
    - Red-orange hues for intermediate data ranges
    - Yellow-white hues for the high data values

Scalar Visualization techniques



- Other colormap designs
- **Diverging:**
  - These are constructed starting from two typically isoluminant hues, just as the isoluminant two-hue colormaps.
  - However, rather than interpolating between the end colors ***cmin*** and ***cmax*** , we now add a third color ***cmid***
- cmin = blue, cmax = red, and cmid = white
- cmin = green, cmax = red, and cmid = bright yellow

Scalar Visualization techniques

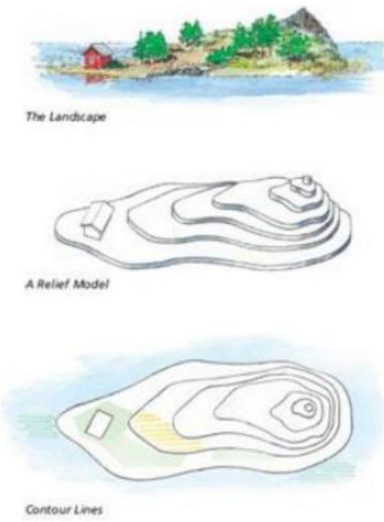
- **Contouring**

Contouring

A contour line C is defined as all points p in a dataset D that have the same scalar value, or isovalue.

For 2D dataset, a contour line is called an isoline.

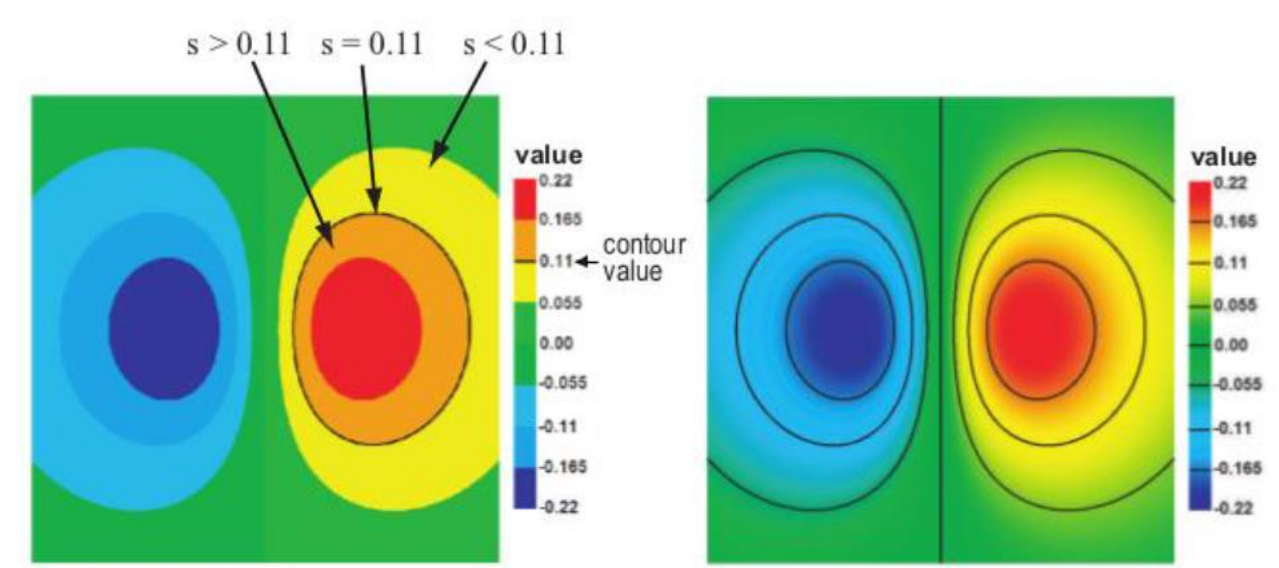
For 3-D dataset, a contour is a 2-D surface, called isosurface.



Source: Data Visualization Principles and Practice , Alexandru C Telea

Scalar Visualization techniques

- **Contouring**



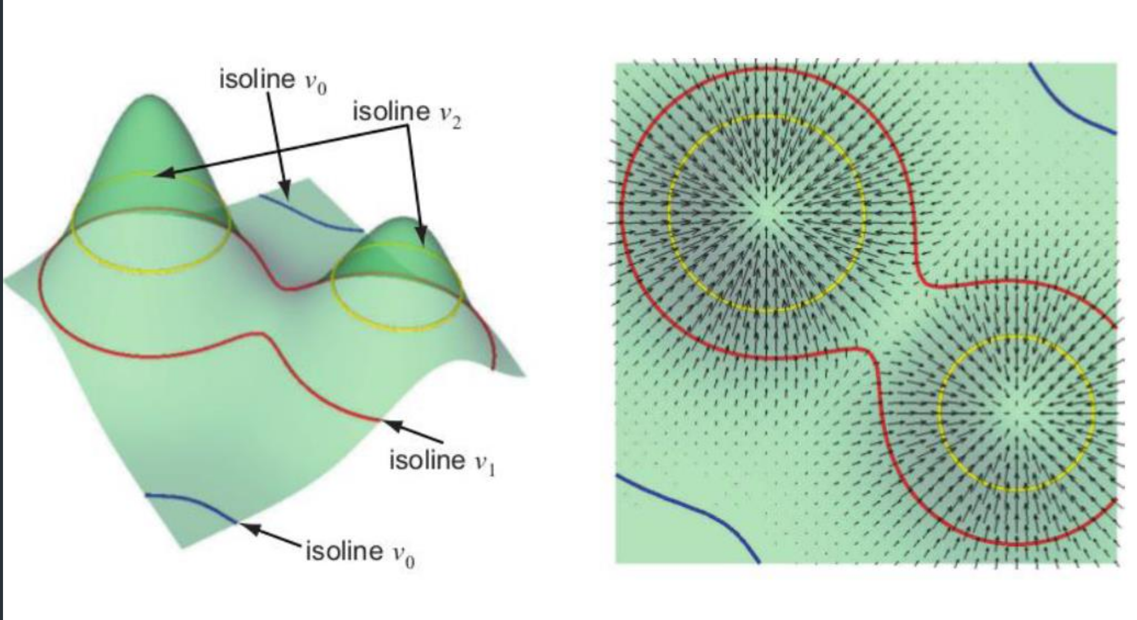
(a) one contour (s=0.11)

(b) 7 contours (s ∈ [-0.165,0.165])

Source: Data Visualization Principles and Practice , Alexandru C Telea

Scalar Visualization techniques

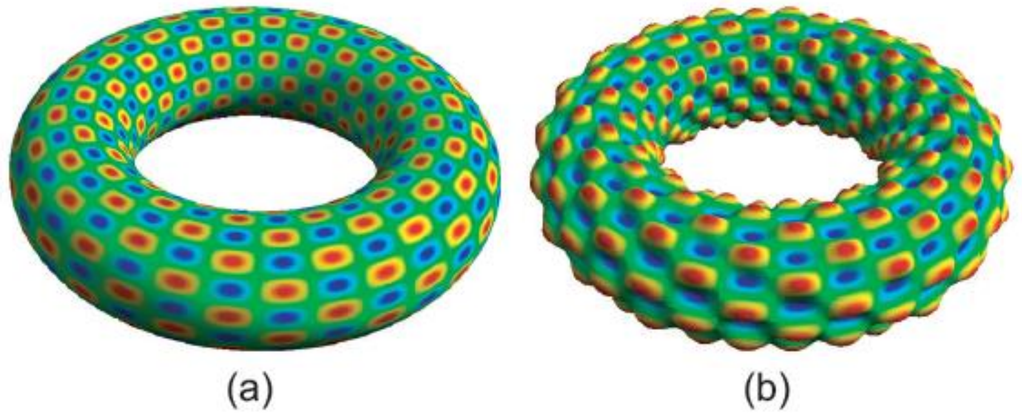
- **Properties of Contouring**



Source: Data Visualization Principles and Practice, Alexandru C Telea

Scalar Visualization techniques

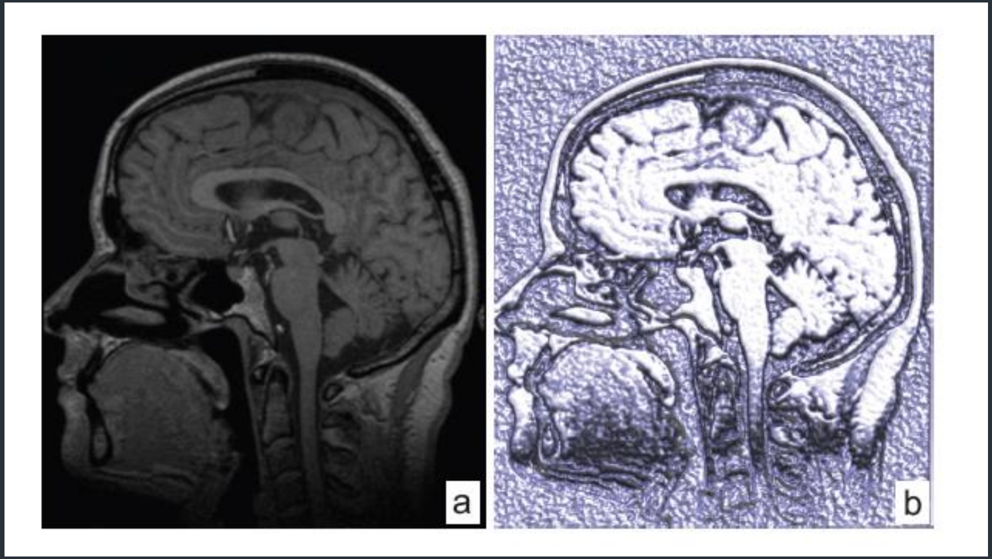
- **Height Plots**
  - Also called *elevation* or *carpet plots*



. (a) Non-planar surface. (b) Height plot over this surface.

Scalar Visualization techniques

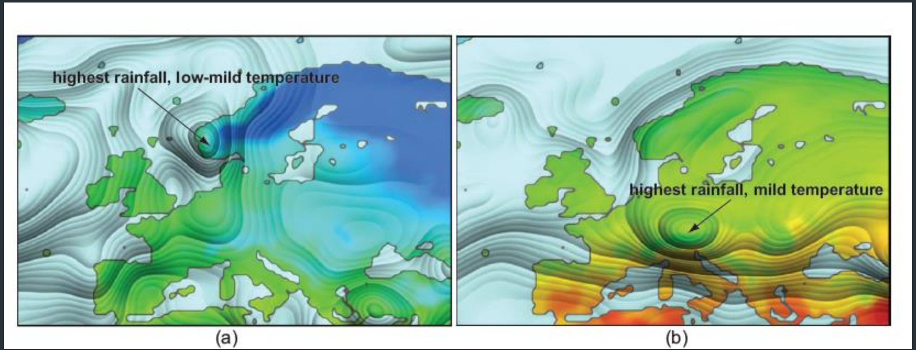
- **Height Plots**
  - Brain CT slice



Source: Data Visualization Principles and Practice , Alexandru C Telea

Scalar Visualization techniques

- **Enridged Plots**
  - It combine the appearance of contour plots and height plots
  - the nested cushion-like shapes that emerge in this type of plot convey a sensation of height which is much stronger than in classical height plots
    - Average rainfall and temperature over Europe for January and July



(a) (b)

Source: Data Visualization Principles and Practice , Alexandru C Telea

Scalar Visualization techniques

- **Color Mapping**
- **Pros**
  - share the advantages of height plots and do not suffer from 3D occlusion problems
- **Cons**
  - making quantitative judgments based on color data can be hard
  - requires carefully designed colormaps, which may be application or even dataset dependent

Scalar Visualization techniques

- **Contor Plots**
- **Pros**
  - effective in communicating precise quantitative values
- **Cons**
  - plots are less intuitive to use
  - they do not create a dense, continuous, image—information is not shown at all points of the input dataset

Scalar Visualization techniques

- **Height Plots**
- **Pros**
  - easy to learn, intuitive to understand, generate continuous images, and show the local gradient of the data in terms of actual slope or shading of the plot
- **Cons**
  - they do not create a dense, continuous, image—information is not shown at all points of the input dataset

Vector Visualization techniques

- Introduction
- Fundamental Mathematical Operators
  - Divergence and Vorticity
  - Vector Glyphs
- Vector Color Coding
- Color coding on 2D surfaces

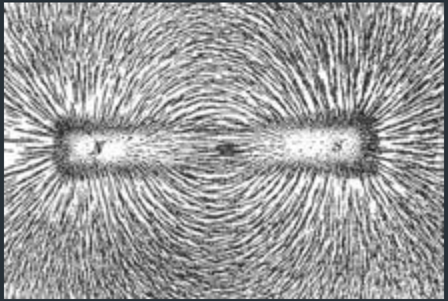
Vector Visualization techniques

- ## Introduction
- A vector is a tuple of n scalar components

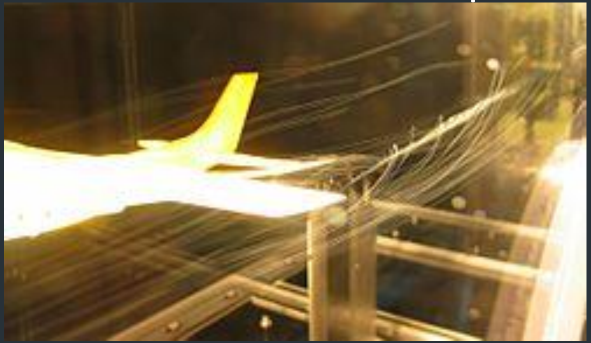
  $v = (v_1, \ldots, v_n), v_i \in R$.
- An n-dimensional vector describes a position, direction, rate of change, or force in R^n .
- Majority of visualization applications deal with data that describes physical phenomena in 2D or 3D space.
- As a consequence, most visualization software defines all vectors to have three components.
- 2D vectors are modeled as 3D vectors with the third (z) component equal to null.

Vector Visualization techniques

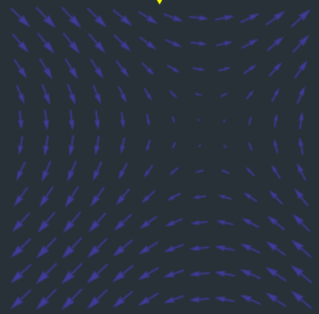
Magnetic field lines of an iron bar



Flow field around an airplane



- **Fundamental mathematical operators**
  - To analyse vector field
    - Vector field
      - **fluid flow**
      - **an assignment of a vector to each point in a subset of space**



Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques

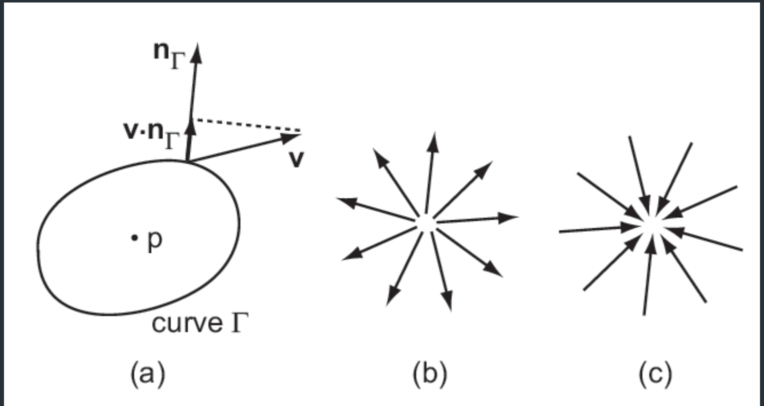
- **Fundamental mathematical operators**
  - visualization applications deal with data that describes physical phenomena in 2D or 3D space
  - most visualization software defines all vectors to have three components
- Divergence and vorticity are important quantities for vector field visualization
  - other types of datasets such as meshes, images, and scalar and tensor fields.

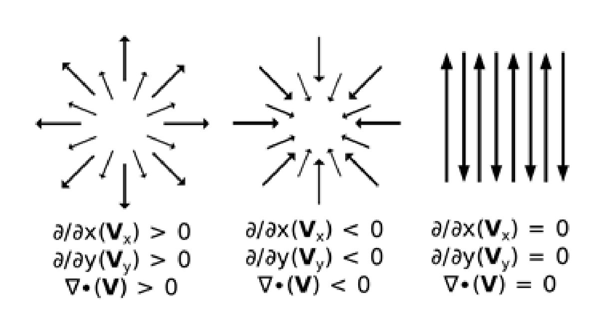
Vector Visualization techniques

- **Divergence**
- Given a vector field $v : R^3 \rightarrow R^3$, the divergence of $v = (v_x, v_y, v_z)^1$ is the scalar quantity

$$\text{div } \mathbf{v} = \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z}$$

Vector Visualization techniques

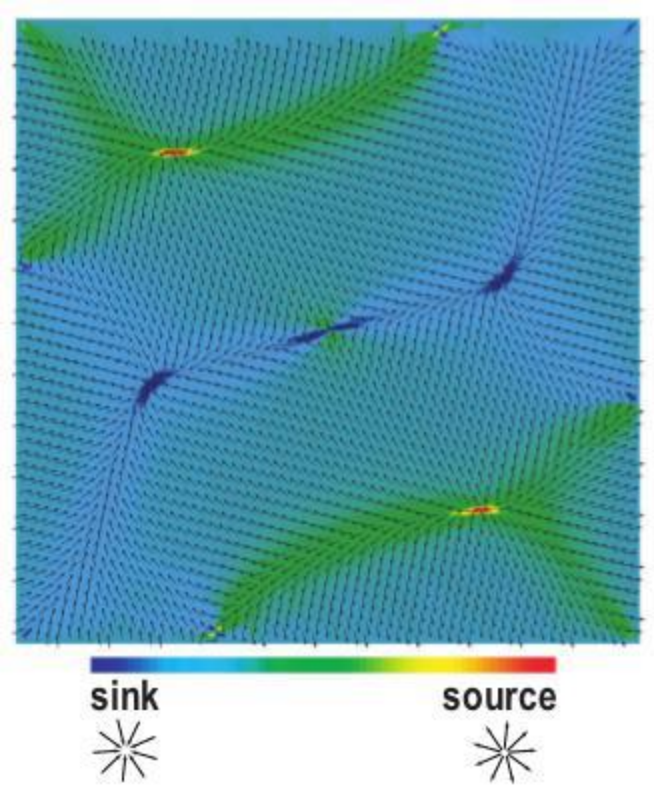




- **Divergence**
- A positive divergence at *p* denotes that mass would spread from *p* outward. Positive divergence points are called *sources*
- A negative divergence at *p* denotes that mass gets sucked into *p*. Negative divergence points are called *sinks*
- A zero divergence at *p* denotes that mass is transported without getting spread or sucked, i.e., without compression or expansion

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques



- **Divergence**
- The example figure shows the divergence of a 2D flow field using a blue-to-red colormap.
- Red areas indicate high positive divergence(sources).
- Blue areas indicate high negative divergence,(sinks).
- We get the image of a flow field that emerges from the sources and ends up in the sinks

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques

- **Vorticity**
- Given a vector field $v : R^3 \rightarrow R^3$, the vorticity of v, also called the ***curl*** or ***rotor*** of v^2 , is the vector quantity.
- The vorticity ***rot v*** of ***v*** is a vector field that is locally perpendicular to the plane of rotation of ***v*** and whose magnitude expresses the speed of angular rotation of ***v*** around ***rot v***.
- Hence, the vorticity vector characterizes the **speed** and **direction of rotation** of a given vector field at every point

Vector Visualization techniques

- **Vorticity**
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- Hence, the vorticity vector characterizes the **speed** and **direction of rotation** of a given vector field at every point

$$\text{rot }\mathbf{v} = \left(\frac{\partial v_z}{\partial y} - \frac{\partial v_y}{\partial z}, \frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x}, \frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y} \right)$$

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques

- Positive Earth Vorticity
- Negative Earth Vorticity
- Positive Curvature Vorticity
- Negative Curvature Vorticity
- Positive Shear Vorticity
- Negative Shear Vorticity

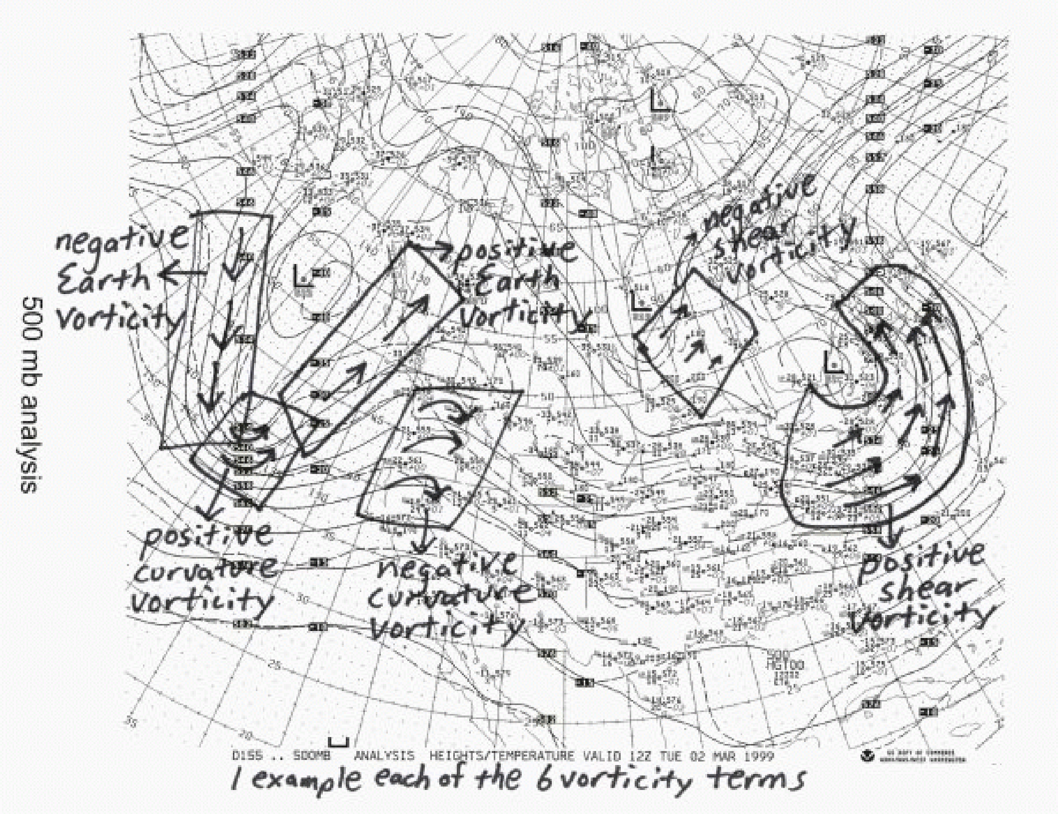
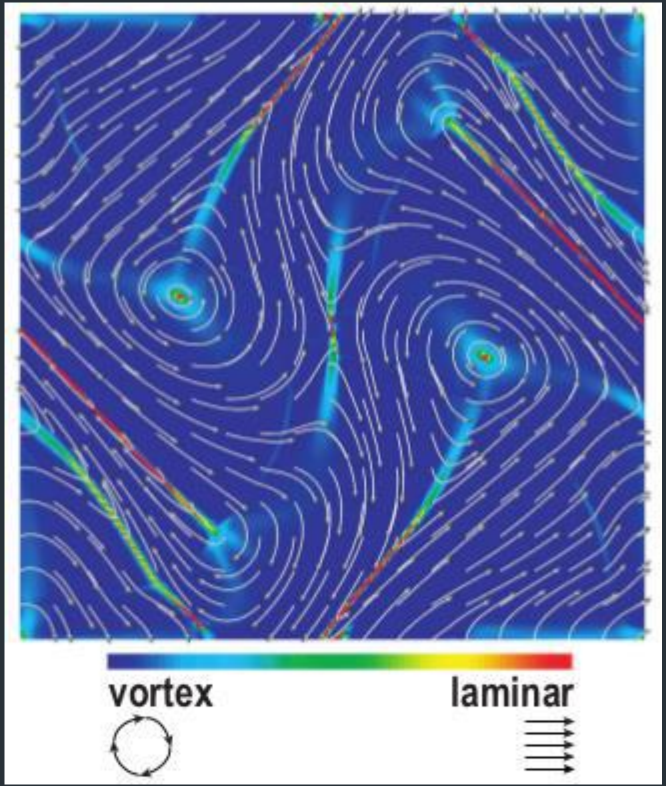


Image Source: https://www.weather.gov/source/zhu/ZHU_Training_Page/Miscellaneous/vorticity/vorticity.html

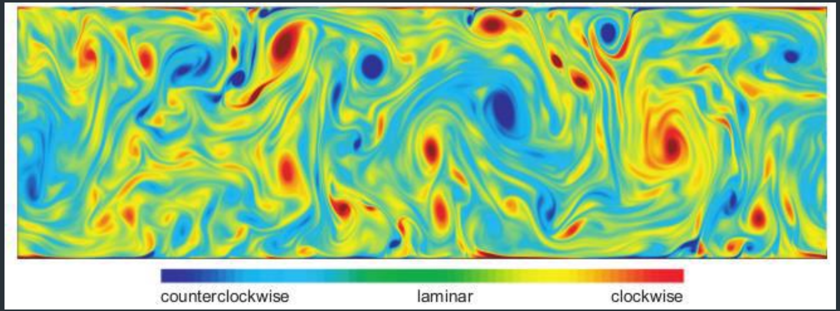
Vector Visualization techniques



- **Vorticity**
- Blue areas indicate low-vorticity, laminar regions.
- Red areas indicate high-vorticity regions.
- Two small circular red spots indicate localized vortices.
- Several elongated thin red strips indicate areas where the vector field quickly changes direction.

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques



- **Vorticity**
- Visualizes the vorticity of a more complex turbulent 2D flow.
- Blue and red indicate respectively counterclockwise and clockwise spinning vortices.
- Green indicates low-vorticity, laminar regions.
- The image clearly conveys the high complexity of the flow

Vector Visualization techniques

- **Vector Glyphs**
- The name *glyph*, meaning “sign” in Greek
- i.e., associating discrete visual signs with individual vector attributes.
- Sign that conveys, by its appearance, properties of the represented vector
  - direction, orientation, and magnitude
- Type of glyphs
  - Line
  - Cone
  - Arrow

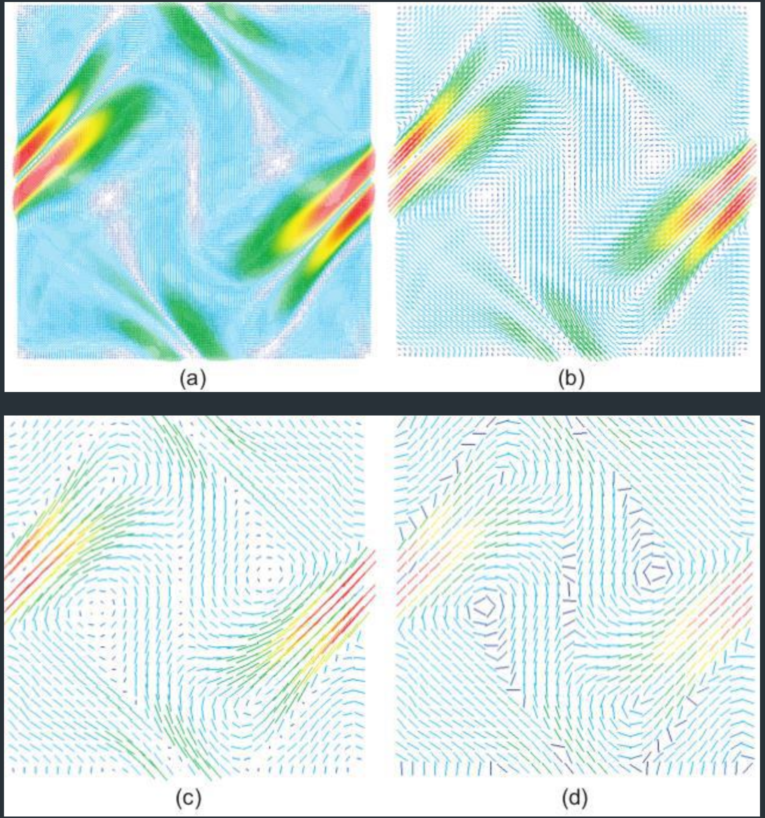
Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques

- **Line Glyphs**
- Lines essentially show the position, direction, and magnitude of a set of vectors.
- $l = (x, x + kv(x))$
  - every sample point $x \in D$
  - ***k* -** the scaling factor
  - $v(x)$ - vector attribute
- Also called hedgehogs

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques



- **Line Glyphs**
- a line glyph, or hedgehog, visualization of a 2D vector field defined on a square domain
- clarity of hedgehog - depends strongly on the glyph scaling factor
- (a) a rate of 2,
- (b) a rate of 4
- (c) a rate of 8
- (d) the vector field is uniformly subsampled at a rate of 8, but the line glyphs are all scaled to the same length

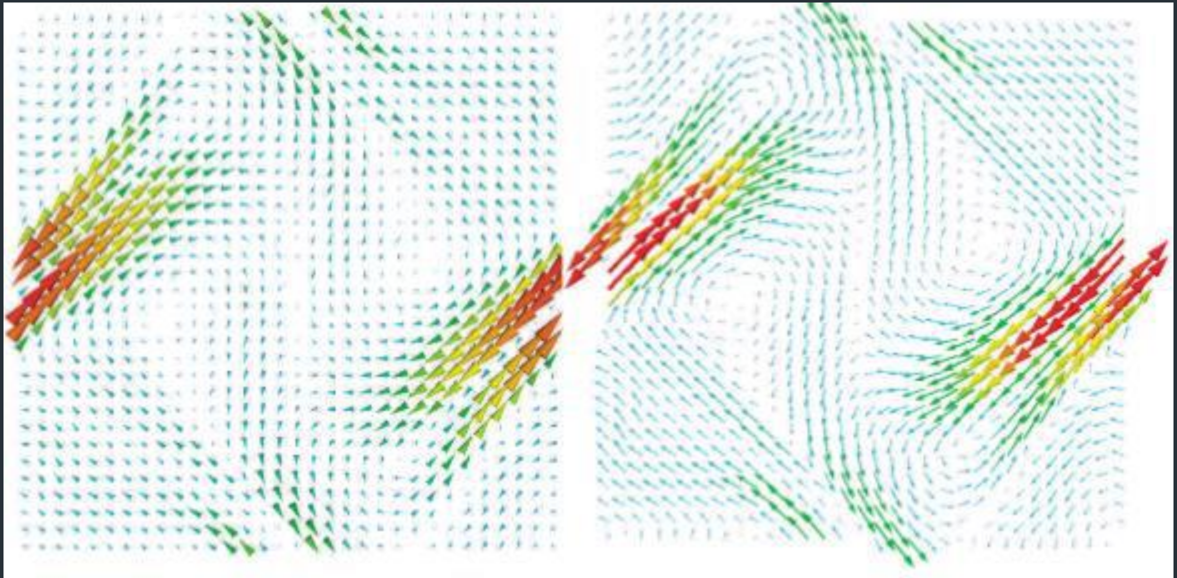
Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques

- **Cone and Arrows Glyphs**
- Cone and arrow glyphs have the advantage of being able to convey a signed direction, whereas lines convey an unsigned direction only
- Glyphs take more space to draw
- Require lower-resolution datasets.

Vector Visualization techniques

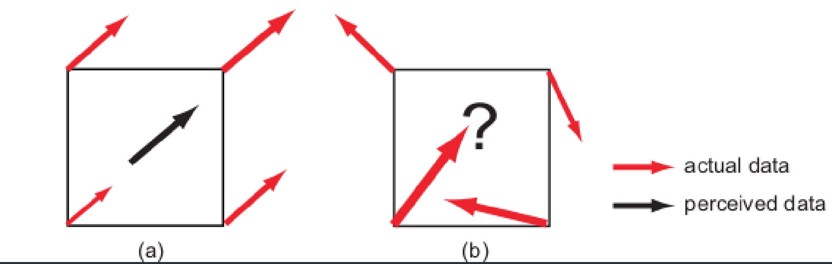
- **Cone and Arrow Glyphs**



(a) (b)

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques

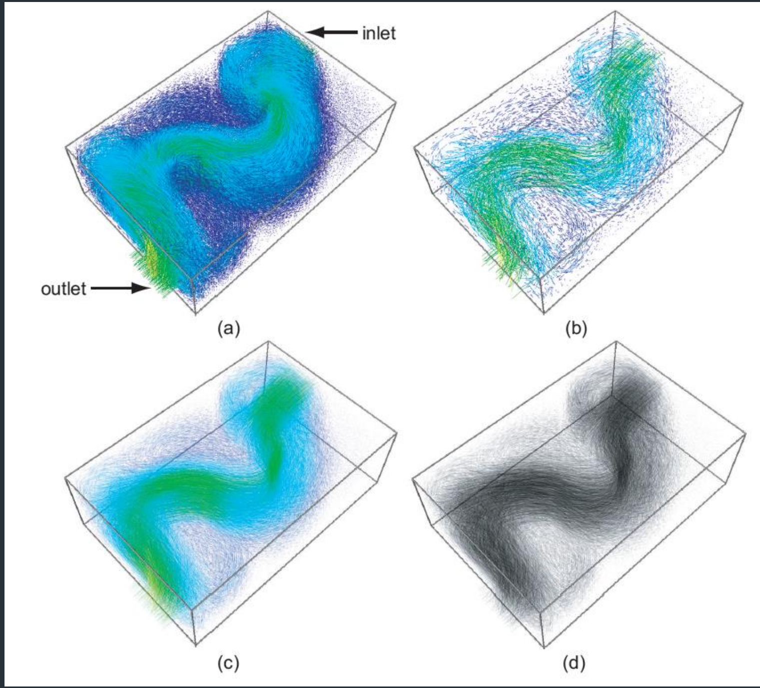


Visual interpolation of vector glyphs.
(a) Small data variations are easily interpolated.
(b) Large data variations create more problems.

- **Vector Glyphs in 2D**
- Consider a zoomed-in detail showing a hedgehog plot over a single cell of a 2D vector field in the figure below.
- In the first case the vector field variation over the displayed cell is quite small.
- There is an increases in magnitude in upper-right direction and orientation.
- In the second case the situation is more problematic

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques



glyphs transparently

Visual effect by using monochrome

- **Vector Glyphs in 3D**
- Flow of water in a Box shaped basin
- an arrow glyph visualization of a 3D vector dataset sampled on a uniform grid containing 128 × 85 × 42 data points that describes the flow of water in a box-shaped basin that has an inlet, located upper-right, and an outlet, located lower-left that cause the sinuous behavior of the flow

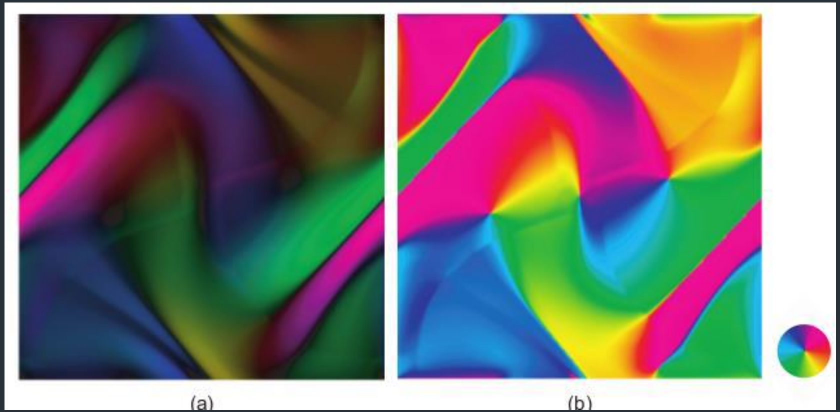
Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques

- **Vector Color Coding**
- Similar to scalar color mapping, vector color coding associates a color with every point of a given surface on which we have defined a vector dataset

Vector Visualization techniques

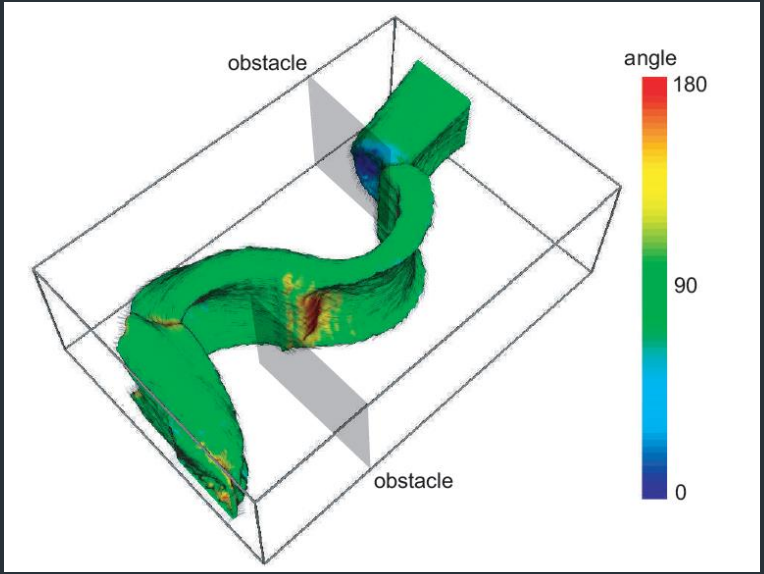
- **Color Coding on 2D Surface**
- Every distinct hue corresponds to a different angle of the color wheel.
  - Red is 0°
  - Magenta is 60°
  - *B*lue is 120°
  - cyan is 180°
  - green is 240°
  - yellow is 300°
  - Saturation is represented as the distance from the wheel center to a given color point.
  - Value is usually represented as a separate one-dimensional “luminance” parameter



a) Orientation and Magnitude
b) Orientation only

Source: Data Visualization Principles and Practice , Alexandru C Telea

Vector Visualization techniques



The angle between the vector and surface normal is encoded via a rainbow colormap

- **Color Coding on 3D Surface**
- the mapping of a 3D orientation to hues on the color wheel is not as simple as in the 2D case

Source: Data Visualization Principles and Practice, Alexandru C Telea