Visualização de Dados
Data Visualization
2021/2022

Mestrado em Engenharia Informática
Mestrado em Informática
Especialização em Informática
Outros mestrados e pós-graduações

1st semester

Course slides

Beatriz Carmo

DI-FCUL

GU-VD-21-4

Scientific Visualization
Vector algorithms

A **vector** is a tuple of *n* scalar components $\mathbf{v} = (v1, \ldots, vn)$, $vi \in$ R.

An *n*-dimensional vector describes, for example, a position, direction, rate of change, or force in R^n.

However, the majority of visualization applications deal with data that describes physical phenomena in two- or three-dimensional space.

[Telea2014]

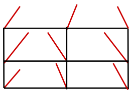
Scientific Visualization
Vector algorithms

The most common algorithms to visualize vectors are: :

- Hedgehogs (*Segmentos orientados)* and glyphs
- Warping (*deformação de formas geométricas*)
- Displacement plots (*superfícies deslocadas*)
- Time animation and trajectories (*animação e trajectórias*)
  - Particle traces (*rastos de partículas*)
  - Streamlines (*linhas de corrente*)

Hedgehogs and glyphs

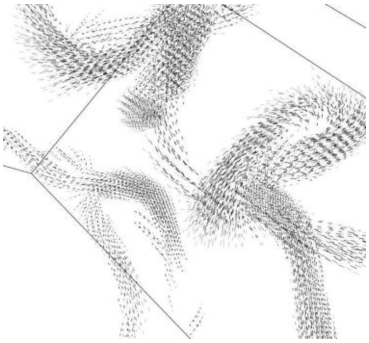
- A natural representation for vector data associated to a grid is to draw an **oriented**, **scaled line** <u>for each grid point</u>:
  - The line begins at the grid point
  - It is oriented according to the direction of vector components
  - And its length is proportional to the vector's length

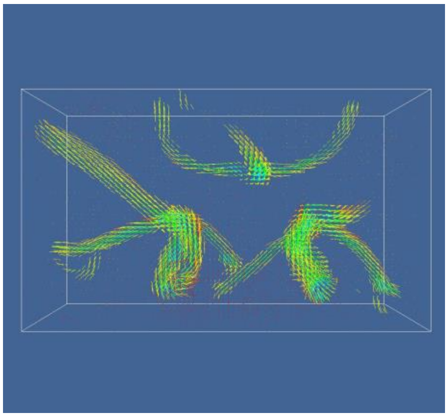


- Disadvantage: it does not represent the orientation (*sentido*) of the vector

- This representation is known as **hedgehog**

Hedgehogs





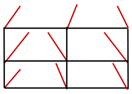
Hedgehogs and glyphs

When there are a <u>large number of vectors,</u> or the <u>scale factor is not appropriated</u> the image may be unintelligible

The scale factor should be

- As big as possible, because it is easier to observe the orientation of the lines if they are longer
- But in order to avoid that the lines intersect their neighbours

A solution is to select a scale that keeps all the segments inside their cells [Telea08]



Hedgehogs and glyphs

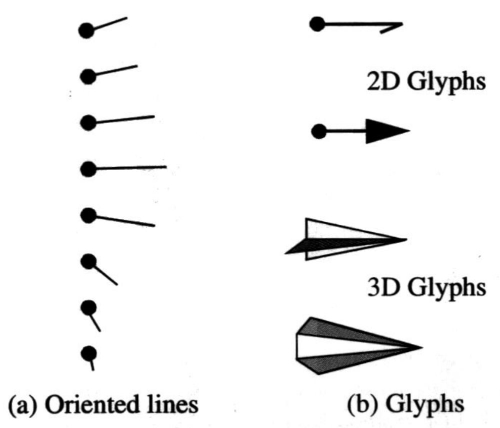
Hedgehogs may be combined with other techniques, for instance, **color mapping**

The lines can be **colored** according to

- The magnitude of the vector (which means two representations for the same variable)
- A scalar variable that is known at the same gridpoints
  - For example, to represent wind with hedgehogs colored according to temperature
  - the number of shares traded in a trading day (stock market)- scalar - and the trend of its growing value - vector data.

Hedgehogs and glyphs

- Symbols may be added to the lines
  - **Arrows** to indicate their direction
  - **Circles** to show their origin
- An hedgehog is an example of a **glyph**



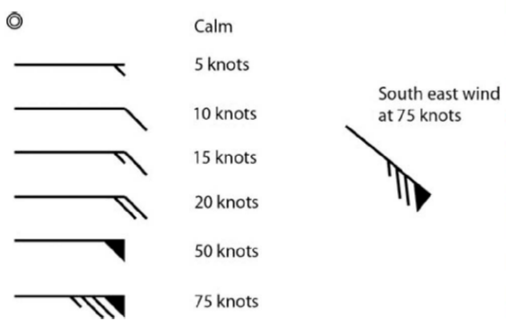
Glyphs

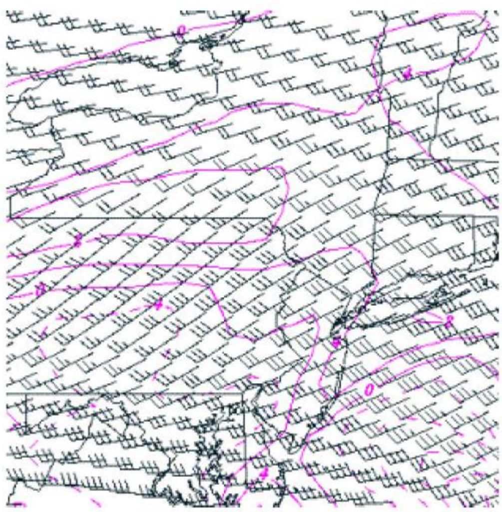
- A glyph is a graphical representation, 2D or 3D, whose size, orientation, shape or graphical attributes can change according to the attributes it represents.

- The use of glyphs explores the human capacity to grasp spatial relationships and changes in shapes to relate multiple variables simultaneously

- Examples of suitable glyphs to represent vector quantities, apart hedgehogs, we have arrows, cones, triangles.

Glyphs drawn on a regular grid



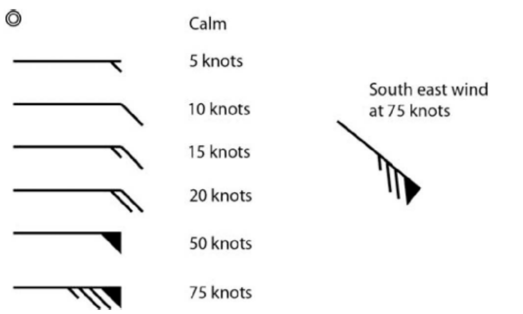


The wind barb glyph code use in meteorological maps [Pilar&Ware2013]

The output from a wind forecast model
http://www.erh.noaa.gov/bgm/casestudy/2002/jan19/Jan19_files/image034.gif
Streamlines and glyphs

Glyphs

The **visual system** is **very good** at judging **<u>relative</u> size**, **color**, or **texture density**, but it is **very poor** at judging **<u>absolute</u> size, color, or density**; these properties are altered by contrast with surrounding elements [Pilar&Ware2013]

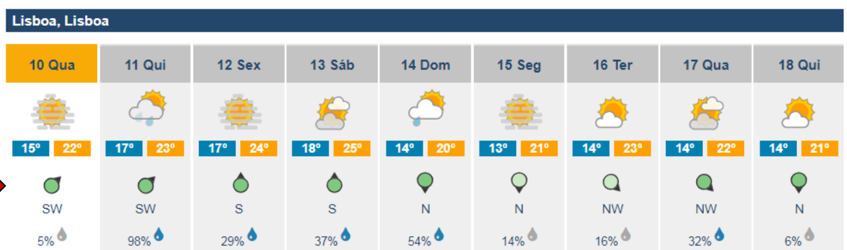


The wind barb glyph do not use size to represent the magnitude of the vector

Glyphs

2016

2018



<u>http://www.ipma.pt/pt/otempo/prev.localidade.hora/index.jsp#Lisboa|Lisboa</u>

Glyphs

- Easy to implement

- The use of hedgehogs and glyphs to represent vector quantities is particularly effective **in 2D** and when it is **not** necessary to use a **high density** of symbols.

In 3D

- It is **not** always **easy** to **understand** the **orientation** of the symbols and the **number of symbols** that can be used without compromising the intelligibility of representation is **limited**.

- Sometimes it is necessary to <u>reduce the number of glyphs represented</u> (subsampling)

- The problem of **occlusion** decreases the understanding of visualization: the glyphs that are ahead hide those that are behind

Glyphs

In 2D or 3D glyphs it may occur the **"visualization lie"** problem [Tufte83]

That is, situations in which a particular representation suggests to the less critical observer a <u>wrong idea</u>

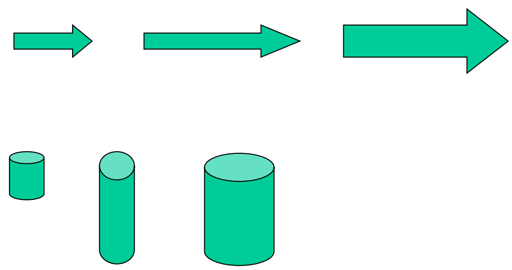
Example

If the magnitude of the vector determines the length of the glyph, but if the scale factor is applied uniformly to two (or three) dimensions of the symbol,

- the shape of the symbol is maintained

- but the effect obtained does not match the desired, ie the perception of the dimension of the glyph is associated to its area (2D symbols) or volume (3D symbols).

Glyphs



Visualization lie

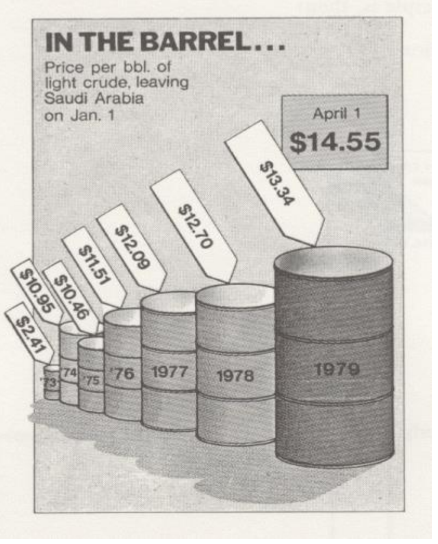
Examples from [Tufte83]

Purchasing power (*poder de compra*) over time

One-dimensional variable represented by varying two dimensions

Visualization lie
Examples from
[Tufte83]

One-dimensional variable represented by varying a volume

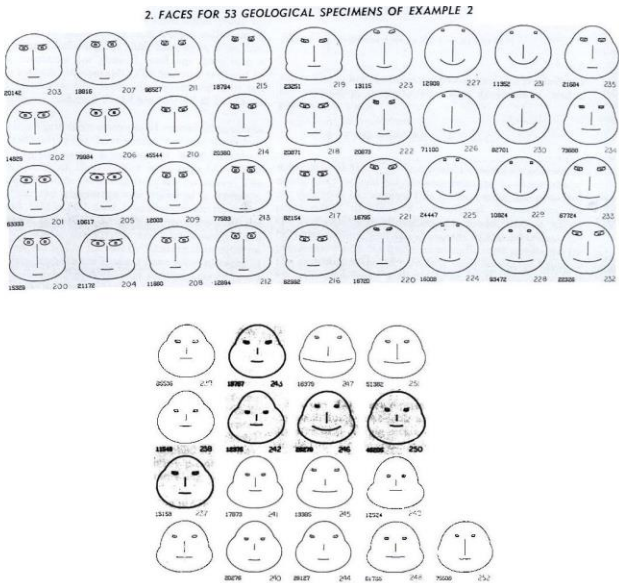


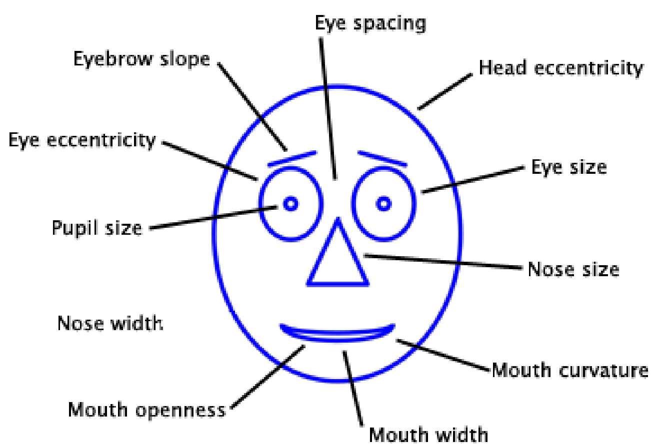
Glyphs (scalars)

- The **glyphs** can be used to visualize **scalars**.

- **Chernoff faces** are an example of simultaneous display of **several variables** (multivariate data) on a limited set of points.
- Each variable is associated to one of the parameters that define the facial expression.

- The following figure represents 53 geological samples.
  In each sample, 12 variables were analyzed.

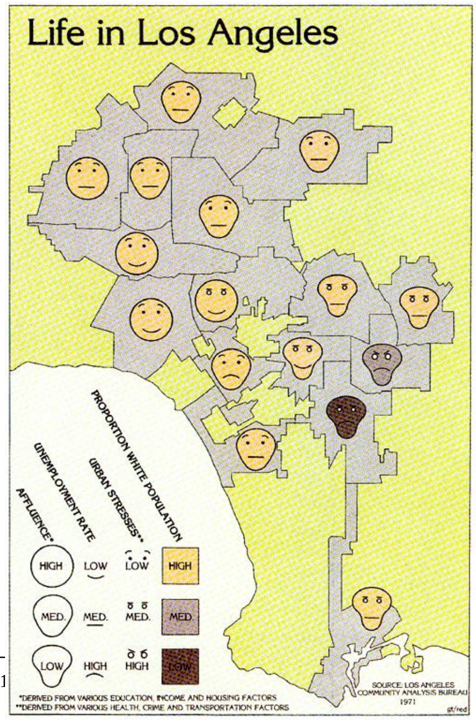

2. FACES FOR 53 GEOLOGICAL SPECIMENS OF EXAMPLE 2


Eye spacing
Eyebrow slope
Head eccentricity
Eye eccentricity
Eye size
Pupil size
Nose size
Nose width
Mouth curvature
Mouth openness
Mouth width

Chernoff Faces

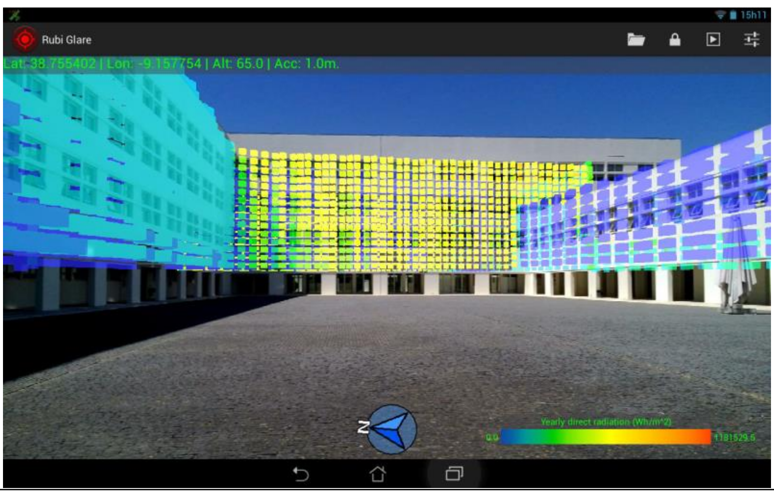
Used parameters:

- Head eccentricity
- Mouth curvature
- Eyes
- Color

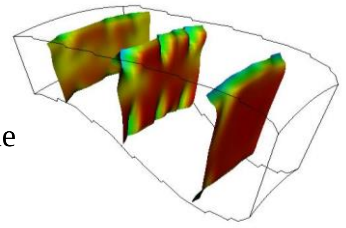


Glyphs (scalars)

The color of the cubes varies according to the values of the scalar variable



Warping (*Deformação de formas geométricas*)



This technique has already been referred to visualize scalars.

In the case of **scalars**, the deformation is made using the **direction of the surface normal**.

In the case of **vectors**, the **vector** provides the two elements required to calculate the deformation: **modulus and direction**.

Warping (*Deformação de formas geométricas*)

The deformations can be applied

- to an object that already exists
  example:
  deforming a structure to show its displacement under the effect of a given load or their vibration.

- To an object created for that purpose
  example: a cutting plane.

Warping (*Deformação de formas geométricas*)

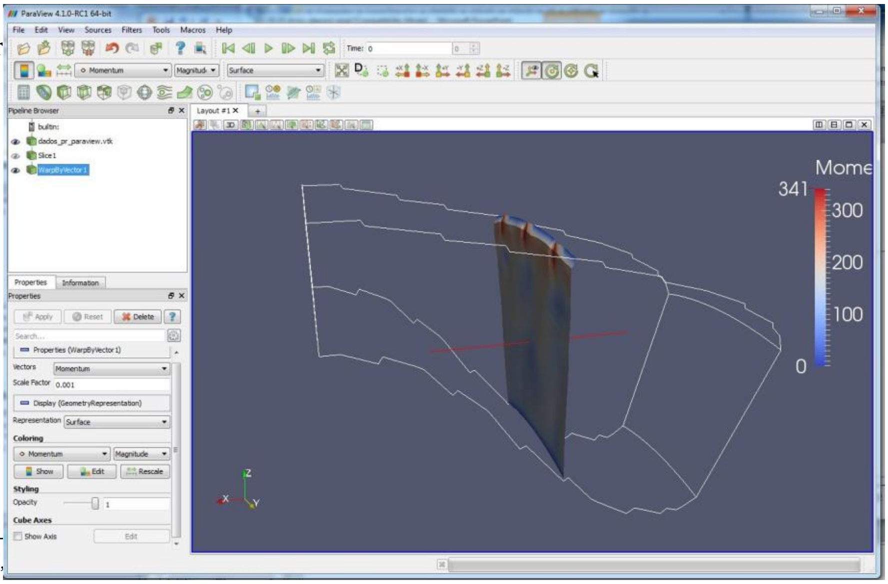
The **scale factor** between the module of the vector and the resulting deformation must be carefully chosen so that:

- the deformations are perceivable

- topological changes do not occur, such as, a surface intersects itself.

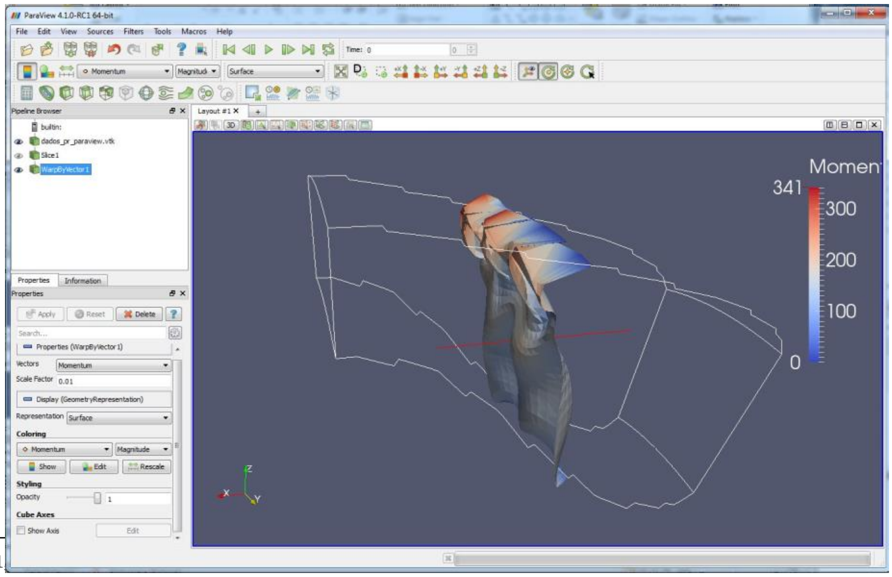
Warping (*Deformação de formas geométricas*)

Scale factor 0.001



Warping (*Deformação de formas geométricas*)

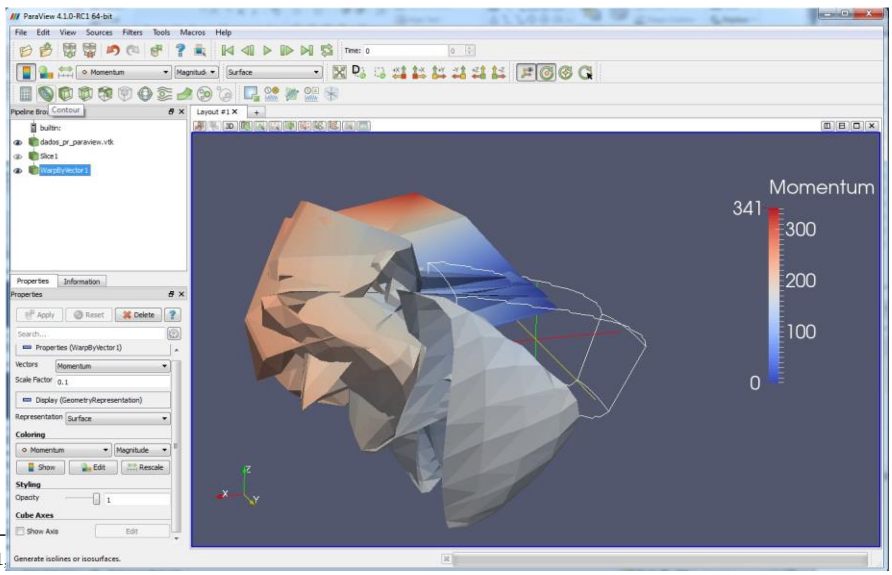
Scale factor
0.01



October 2021

Warping (*Deformação de formas geométricas*)

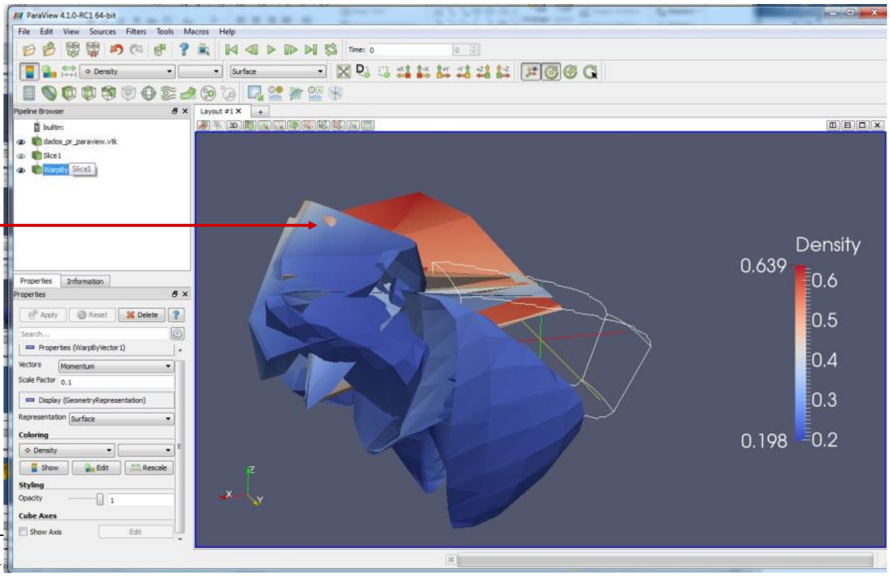
Scale factor
0.1



October 2021

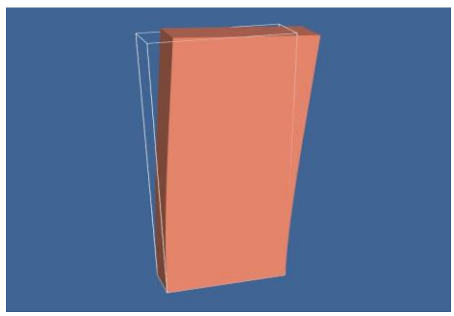
Warping (*Deformação de formas geométricas*)

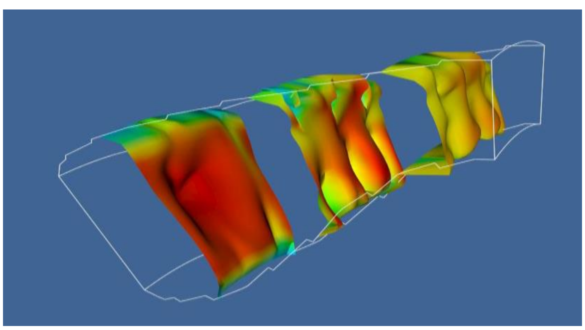
Scale factor
0.1



October 2021

Warping (*Deformação de formas geométricas*)





Displacement plots (*Superfícies deslocadas*)

- This technique has **similarities** with either **carpet plots** for scalars or **warping** for vectors

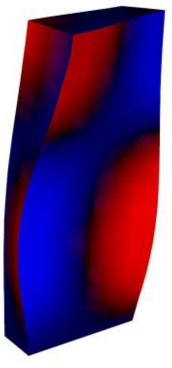
- In this case a vector field is represented on a surface,
  - by first **converting** it **into a scalar field**, through the inner product of the **vector normal to the surface**,
  - and then generating a carpet plot of the scalar field.

If the inner product [u.v = || u || || v || cos (u, v)] is
- positive, the offset is in the direction of normal
- negative, the displacement is in the opposite direction of normal

Displacement plots (*Superfícies deslocadas*)

Example:

This technique is particularly useful in the study of vibrations.
*By making the representation of the displacement field surface, called **modal lines** (lines where the **displacement is zero**) become evident.*



In the figure
The modal lines are represented in **black**.
The bright areas correspond to the values at the beginning and end of the lookup table (correspond to -1 or 1 dot product).

Time animation and trajectories/paths
(*animação e trajectórias*)

- When the variable we want to visualize is **speed**, it is interesting to visualize its **effect over time**, that is, to visualize the motion of an object where the vector speed is applied.

- This technique (the effect of applying a vector field to an object/particle) can be applied to any vector field.

Time animation and trajectories/paths
(*animação e trajectórias*)

There are two ways to show time evolution:

- through an **animation**, in which time is displayed explicitly, giving an illusion of motion

Each image corresponds to an instant in time

- by **drawing paths**:

The path can be imagined as being the result of the <u>motion captured in a photo</u> taken with a very large exposure time.

Add in the same image positions related to different instants in time

Drawing paths
Analogy with photos

- Multiple exposure
  - images captured at different instants are superimposed

At the end displays a fractionated path

A multiple exposure image of a lunar eclipse taken over Hayward, California in 2004.

Drawing paths
Analogy with photos

- Long exposure
  - A single exposure for an extended period

- At the end a continuous path is displayed

http://www.flickr.com/photos/daramul/2085968099/in/pool-longexposure/

Time animation and trajectories/paths
(*animação e trajectórias*)

Both for time animation and paths we are dealing with a problem that requires a numerical integration

We know the speed

$$\vec{v} = dx/dt$$

And we want to get the position x in time t

$$x(t) = \int_t \vec{v}\, dt$$

Time animation and trajectories/paths
(*animação e trajectórias*)

- **Numerical integration** is a process that involves an error which, in some cases, can lead to coarse results.
- The amplitude of the time interval (Δt) considered between successive steps can be decisive

  If the interval is too large, some speed variations may not be detected

Time animation and trajectories/paths
(*animação e trajectórias*)

Among the numerical integration methods, the most used are Euler method and Runge-Kutta method

Calculates position x_{i+1} based on the previous position

$$x_{i+1} = x_i + v_i \,.\, \Delta t$$

Calculates position x_{i+1} based on two instants in time

$$x_{i+1} = x_i + \Delta t /2 \,.\, (v_i + v_{i+1})$$

- At each time i, vector v_i corresponds to the value of the vector field at position x_i

(v_i may be calculated by interpolation of the vector field in the cell grid that contains x_i)

Runge-Kutta method

- Approximates the vector field v, between two sample points x_i and x_{i+1} with the **average value** $(v_i + v_{i+1})/2$.
- Therefore, it produces <u>more accurate results</u> than Euler method

In Runge-Kutta method, v_{i+1} is calculated using Euler method:

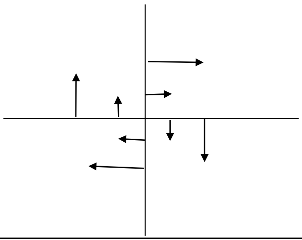
–First, position x_{i+1} is calculated using Euler method to obtain v_{i+1}

–Then, vi and v_{i+1} are used to calculate the new position x_{i+1}

Time animation and trajectories/paths
(*animação e trajectórias*)

Euler method is not accurate enough for some applications

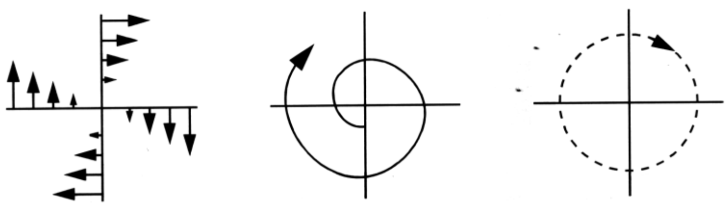
For instance, when the velocity field describes a <u>perfect rotation</u> about a <u>central point</u>



Time animation and trajectories/paths
(*animação e trajectórias*)

- Positions calculated with Euler method will diverge and generate spirals (b)

- While Runge Kutta method generates circles (c)



(a) Rotational vector field (b) Euler's method (c) Runge-Kutta

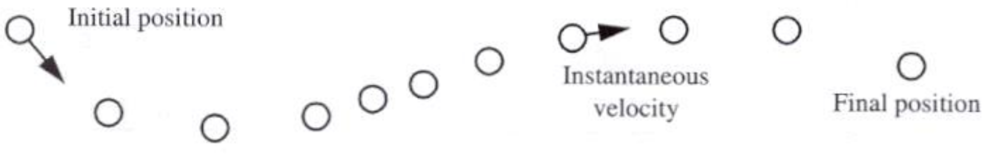
[Schroeder06]

Time animation and trajectories/paths
(*animação e trajectórias*)

- These techniques can be applied, for instance, to the visualization of the flow of air in a room
- In the physical world the phenomenon is noticeable but not visible unless there is dust in sufficient quantity
- These visualization techniques produce images that correspond to the motion of particles in the air, ignoring the action of gravity.

Particle traces (*rastos de partículas*)

- Particle traces display on a single image the positions calculated over a given period
- These positions may be connected by a line

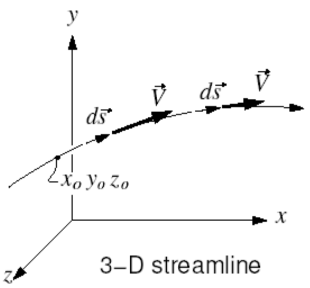


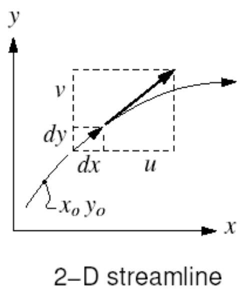
The positions displayed are not equally spaced, although they were calculated in constant time intervals

Streamlines (*linhas de corrente*)

- **Streamlines** (***linhas de corrente***) are another representation for paths
- For <u>given instant in time</u>, t, they correspond to lines that are tangent to the vector field at each point of the grid
- In the case of a stationary field, that is a time independent vector field, this representaion is equivalent to particle traces

Streamlines (*linhas de corrente*)





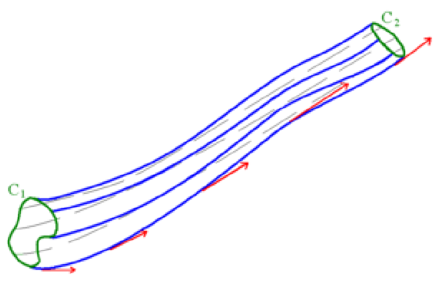
•

Streamlines and streamtubes

• Solid blue lines and broken grey lines represent the streamlines.

• The red arrows show the direction and magnitude of the flow velocity. These arrows are tangential to the streamline.

• The group of streamlines enclose the green curves (C1 and C2) to form a **streamtube**.



Time animation and trajectories/paths

Summing up:

– Stationary fields (campos estacionários): **Streamlines** and **particle traces** are equivalent and also equivalent to an animation

– Non-stationary fields:

• **Streamlines** and **particle traces** are not equivalent

• **Particle traces** and **animations** are equivalent

Streamlines and streamtubes

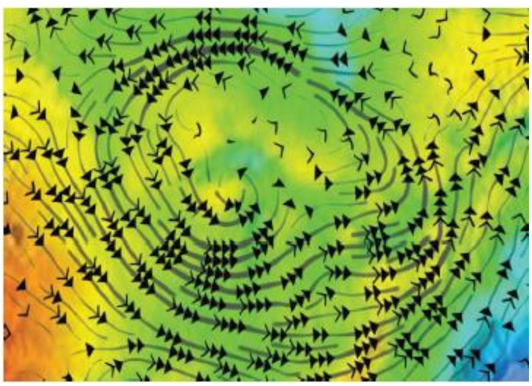
Any of these representations can:

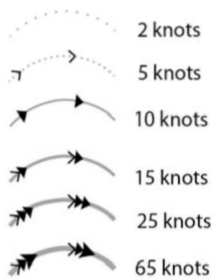
- be colored to represent a scalar
- be "adorned" with glyphs containing information about one or more variables.

For instance, consider the visualization of airflow with streamlines

- colored according to the magnitude of velocity
- "adorned" with glyphs whose size and orientation represent the acceleration and whose color represents the pressure.

Representing Flow Patterns by Using Streamlines with Glyphs





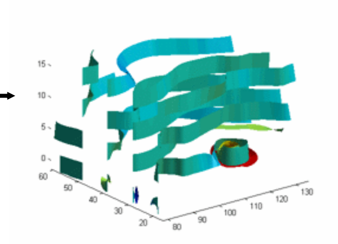
Arrow glyph code

“A colored background image consisting of a map of North America was used because the designs are intended to allow for a color-coded background” [Pilar&Ware2013]

Streamlines and streamtubes

- Streamline representations can be extended:
  - Streamribbons (*fitas de corrente*)
  - Streamsurfaces (*superfícies de corrente*)

    (Streamtubes are a particular case of streamsurfaces)

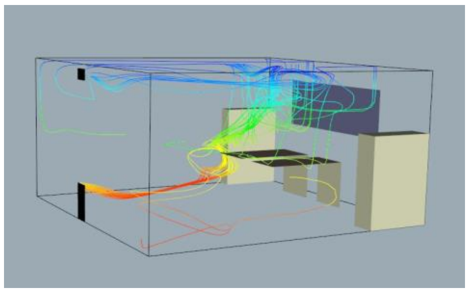


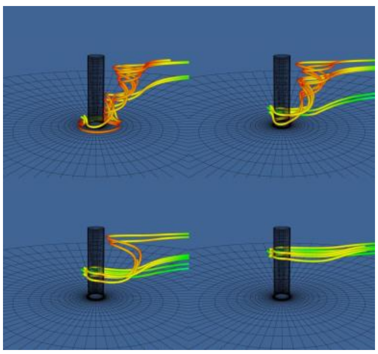
http://www.mathworks.com/help/techdoc/ref/streamribbon.html

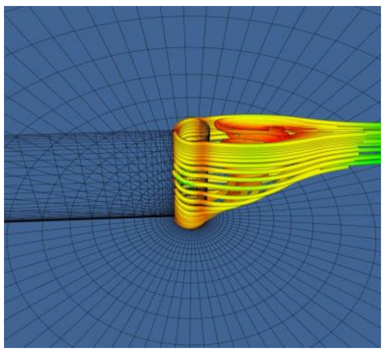
Streamribbons and streamsurfaces are extensions of streamlines that allow the visualization of additional information.

For instance the thickness of the streamtubes can vary according to a scalar value

Streamlines and streamtubes







Referências

- “The Visualization Toolkit – an Object-Oriented Approach to 3D Graphics”, W. Schroeder, K. Martin, B. Lorensen, Prentice Hall PTR,
  2ª edição, 1998, 4ª edição, 2006
- “The VTK User’s Guide”, Kitware, Inc., 2006
- Alexandru Telea, “Data Visualization, Pinciples and Practice”, AK Peters, 2014
- http://www.vtk.org
- E. R. Tufte, "The Visual Display of Quantitative Information", Graphics Press, Cheshire, CT, 1990
- João Cunha, Guiões Visualização, DI-FCUL
- David H.F. Pilar and Colin Ware, Representing Flow Patterns by Using Streamlines with Glyphs, IEEE Transactions on Visualization and Computer Graphics, vol. 19(8), pp1331-1341, 2013

Exercises

1

Describe a way to represent a vector quantity

a) at a given instant of time.

b) within a period of time.

[Descreva uma forma de representação de uma grandeza vectorial

a) num dado instante de tempo.

b) num intervalo de tempo.]

2

Surface deformation (warp) algorithms can be used either to represent scalar quantities or to represent vector quantities. Explain how they are applied in both cases.

[Os algoritmos de deformação de superfícies (warp) podem ser usados quer para representar grandezas escalares, quer para representar grandezas vectoriais. Explique como são aplicados num e noutro caso.]

3

a) What are icons or glyphs?

b) Design an icon suitable for simultaneously representing two vector quantities and a scalar quantity defined on the same grid. Draw the icon for 3 different situations (3 points of a hypothetical grid) in order to show the ability of the icon to be represented. (Remember that an icon can be a composition of several geometric figures**)**

[a) O que são ícones ou *glyphs* ?

b) Conceba um ícone adequado para representar simultaneamente duas grandezas vectoriais e uma grandeza escalar definidas sobre a mesma grelha. Desenhe o ícone para 3 situações distintas (3 pontos de uma grelha hipotética) por forma a evidenciar a capacidade da representação do ícone. (Lembre-se que um ícone pode ser composição de várias figuras geométricas)]