

# Survey on Glyph based Visualization

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## Abstract

Today, a vast amount of data is available and must be shown in a meaningful way in order to get the desired information in an appropriate time. Research in the field of visualization attempts to handle this information and as a result many different visualization techniques have been developed. This survey gives an overview of glyphs in visualization. First, we give a short introduction in semiology, to get a better understanding of signs. Then we will describe different types of glyphs together with their properties. Subsequently, we will give applications areas for the different glyphs and conclude the work with design guidelines.

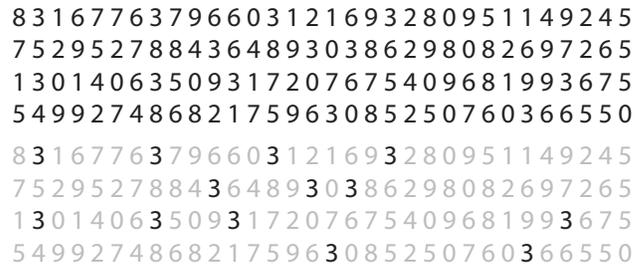
## 1 Introduction

Currently data acquisition tools such as 3D-Scanner, digital cameras and many more are capable of acquiring heavy loads of data. Some of them use multiple dimensions to retain the properties of measured real world data. This has led to many approaches of visualizing different data to best fit the needs of users. Movements toward better representations of data are designed to provide the user with tools in order to perceive the characteristics of the vast amount of data presented. If data size and dimension would increase further, it would be even more time consuming for the user to extract the relevant information.

The need for visualizations comes from different scientific areas and therefore various visualization styles have been developed. The underlying data of these visualizations can be multivariate in their nature. Meaning that different measurements lead to one resulting sample. This is the cause of higher dimensionalities in these data sets. For example pressure, temperature, wind velocity and precipitation can be acquired as meteorological data. Other data sets can contain density measurements of tissue as they are used for medical visualizations. This amount of data cannot be processed by only going through the different measurements. Thus scientific research has shown that one way of dealing with this data is to visualize them in different ways [Bürger and Hauser 2007].

Visual data representations make use of the high bandwidth of information that can be processed through the visual sense. No other human sensory system can deal with such a vast amount of information. But not all the data can be perceived at once during the investigation of a visualization. Shneiderman [1996] presented the following Visual Information Seeking Mantra, which describes the different steps that are needed to perceive most of the information shown in a visualization:

Overview first, zoom and filter, then details-on-demand.



8 3 1 6 7 7 6 3 7 9 6 6 0 3 1 2 1 6 9 3 2 8 0 9 5 1 1 4 9 2 4 5  
7 5 2 9 5 2 7 8 8 4 3 6 4 8 9 3 0 3 8 6 2 9 8 0 8 2 6 9 7 2 6 5  
1 3 0 1 4 0 6 3 5 0 9 3 1 7 2 0 7 6 7 5 4 0 9 6 8 1 9 9 3 6 7 5  
5 4 9 9 2 7 4 8 6 8 2 1 7 5 9 6 3 0 8 5 2 5 0 7 6 0 3 6 6 5 5 0  
8 3 1 6 7 7 6 3 7 9 6 6 0 3 1 2 1 6 9 3 2 8 0 9 5 1 1 4 9 2 4 5  
7 5 2 9 5 2 7 8 8 4 3 6 4 8 9 3 0 3 8 6 2 9 8 0 8 2 6 9 7 2 6 5  
1 3 0 1 4 0 6 3 5 0 9 3 1 7 2 0 7 6 7 5 4 0 9 6 8 1 9 9 3 6 7 5  
5 4 9 9 2 7 4 8 6 8 2 1 7 5 9 6 3 0 8 5 2 5 0 7 6 0 3 6 6 5 5 0

Figure 1: Try to count the 3's in both images. **Top:** The task leads to a sequential search. This is not preattentive. **Bottom:** Preattentive processing of the 3's through grayscale coding.

This leads to Section 2 of the paper where the perception of signs is discussed. In this chapter preattentive as well as attentive processing is explained as important perceptual cues toward an easier readability of glyphs.

The rest of the paper focuses on visualization through glyph representations. Glyphs are sign-like shapes which map the properties of the multidimensional inputs to their shape, color, size, and positions. Which properties of the glyph are changed during this mapping process is dependent on the set of glyphs used for the visualization. Section 3 describes some types of glyphs. The field of applications of the presented glyphs is given in Section 4 and a discussion of the glyph design follows in Section 5. The discussion includes design guidelines that summarize this work and Section 6 concludes the paper.

## 2 Perception of signs

Semiotic as defined by Saussure [1959] is “A science that studies the life of signs within society [...]”. As glyphs can be interpreted as signs, the study of semiotics leads to design guidelines for glyphs in order to increase, for example, their expression. The research area of semiotics is vast, so this chapter focuses on (visual) perception of signs.

If glyphs are used for visualization, the user should focus on important areas of the underlying data. Just by looking at a visualization briefly, specific information could “pop out”. This popping out is the effect of the preattentive processing of the visual system. Preattentive processing is done directly in our visual system and therefore is processed very fast. To get a better understanding of what preattentive processing means, try to count the 3's in Figure 1 (top). Normally, you have to search sequentially through all rows to count all 3's. But if you try the same with the bottom image, you will preattentively see all the 3's without scanning over any rows [Ware 2004]. This is due to the change of contrast of all numbers except the 3's.

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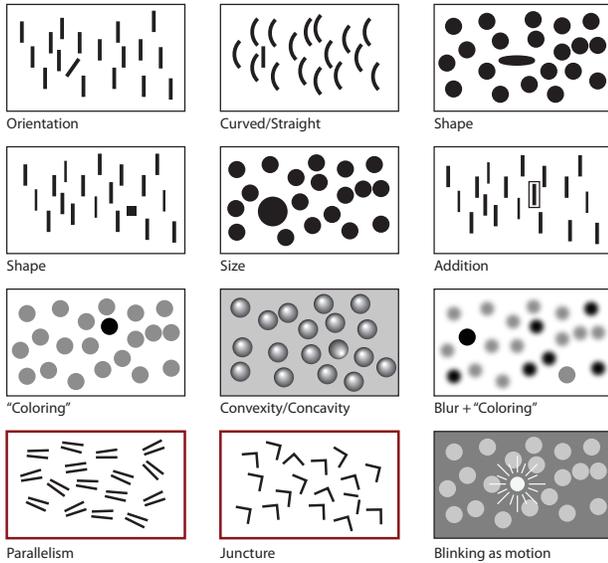


Figure 2: Some different preattentive features are shown here. Juncture and Parallelism of lines (bottom left and red framed) cannot be preattentively processed. It is very hard to find the two parallel lines in the bottom left image. This is the same for the broken corner in the middle image of the last row. Therefore such features shouldn't be used during the design of distinguishable glyphs [Ware 2004].

Many studies have investigated the field of preattentive processing [Treisman and Gormican 1988; Quinlan and Humphreys 1987; Duncan and Humphreys 1989; Chau and Yeh 1995; Callaghan 1989; Bauer et al. 1996]. The results of these studies can directly be used to design meaningful glyphs that represent multidimensional data in a more accurate way. Some features that were found to be preattentively processed are according to Ware [2004]:

- **Form:** Orientation/length/width/collinearity of a line, size, curvature, spatial grouping, blur, additional marks, numerosity
- **Color:** hue, intensity
- **Spatial position:** 2D position, depth cues, convex/concave shape from the shading
- **Motion:** flicker, direction of motion

The effect of preattentive features can easily be understood if they are shown in images. Figure 2 shows some of the above mentioned features. Juncture and Parallelism of lines (images highlighted with red frames) as shown in the last row of the same Figure are not distinctively perceivable. This tells us not to use them during the design of glyphs as cues of attraction.

Combinations of preattentively processed features can lead to unwanted effects as shown in Figure 3. The problem is that some of these features “pop out” more than others and one can concentrate only on one feature at a time. If features are combined to represent some data one should be aware which information to convey with preattentive features. Otherwise this could lead to a slow interpretation of the data, or the viewer focuses on wrong parts of the data.

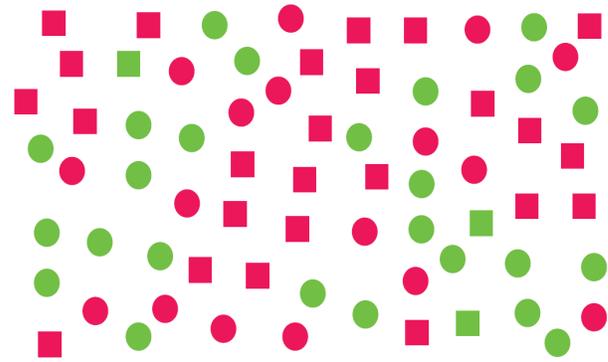


Figure 3: The different shapes are not distinctively perceivable, because the coloring is more attractive [Ware 2004].

### 3 Types of Glyphs

In this section different types of glyphs used for visualization of multivariate data are presented. There are many types of glyphs used in different fields of applications like medical and flow visualization, material science or meteorology, but not all of them can be presented in this work. Moreover, we want to give an outline of the different types of glyphs together with their properties.

Ropinski and Preim [2008] proposed **basic** and **composite** glyphs. According to their classification basic glyphs make use of geometric objects like arrows (Section 3.1), cuboids, cylinders, ellipsoids (Section 3.2) or Superquadrics (Section 3.3). The parameters are mapped on the geometric properties of these basic objects. In contrast, Composite glyphs use basic geometric forms to build more complex representations of the data. They are often used to represent multivariate data, because each data type can be mapped to another basic object of the complex glyph. For this reason the parameter cannot directly be mapped to the parameters of the basic objects but have to take relationships between the data dimensions into account [Ropinski and Preim 2008]. In Section 3.4 and 3.5 two different composite glyphs will be explained in detail.

#### 3.1 Arrows

Arrows are simple and natural glyphs used to visualize data with one main direction. Since arrows are often used in human made environments (e.g. traffic signs, navigation systems, drawings, concepts, diagrams, etc.) they are easy to read and understand.

An arrow glyph provides parameter mapping to its length and width in the 2D case, but mostly only the length is used to map information like velocity onto this glyph. Furthermore, one main direction and a spatial position can be displayed. Figure 4 shows different arrow glyphs for the visualization of wind velocities and vector fields.

Arrow glyphs can be used to visualize vector fields, because the mapping of these types of data onto an arrow is straight forward. If such glyphs are used for dense data, occlusions will occur. To resolve such overlappings is not always easy. Another problem arises with the alignment of the arrows.

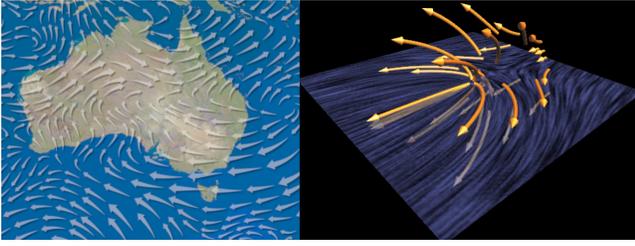


Figure 4: The image on the left is a weather visualization of Australia where the arrows indicate wind directions and velocities [Turk and Banks 1996]. The image on the right side shows a simplified vector field visualization using arrows with an additional streamline visualization [Telea and van Wijk 1999].

Simply aligning them on a grid can reduce the clarity, because no contours can be found throughout all arrows [Field et al. 1993] as presented in Figure 5 [Laidlaw et al. 2005]. The length of an arrow can be used to represent a scalar value of the given information (e.g. the wind velocity). These values can be distributed over a large interval which means that the smallest and largest value are numerically far away from each other. Thus the arrows in the visualization have different sizes and the direction of the smallest can hardly be seen (see Figure 5 (c) and (d)). One way to resolve this problem is to use streamlines in addition to the arrows, or animate the arrows in a flow field if the given data set includes time dependent data [Laidlaw et al. 2005].

### 3.2 Quadrics

Quadrics are  $N$ -dimensional hypersurfaces embedded in the  $(N+1)$ -dimensional space. For visualization purposes only 2- and 3-dimensional Quadric shapes are used. Some of the forms that are representable are different conic sections like ellipses in 2D and ellipsoids, spheres and elliptic cylinders in 3D. The equations for 2D/3D ellipsoids are given in Equation 1.

$$\begin{aligned} \left(\frac{x}{A}\right)^2 + \left(\frac{y}{B}\right)^2 &= 1 \\ \left(\frac{x}{A}\right)^2 + \left(\frac{y}{B}\right)^2 + \left(\frac{z}{C}\right)^2 &= 1 \end{aligned} \quad (1)$$

Parameters can be mapped onto the axis of these glyphs. This results in stretched and squeezed shapes as presented in Figure 6. For illustrative purposes only the 2D case of an ellipse is presented. In the 3D case, an additional parameter can be used to map another property on the glyph shape.

Ellipsoids are useful if the given data set is oriented in space, but no signed orientation is given [Kindlmann 2004] because their shape is  $180^\circ$  rotational symmetric. If ellipsoids are rotated they must have one major axis aligned with the given angle from the data. Therefore only the minor axis can be used to map a parameter and has to be shorter or equal to the major axis. Otherwise the shapes would be indistinguishable, because one cannot tell which axis is the major axis in the isotropic case (see Figure 6).

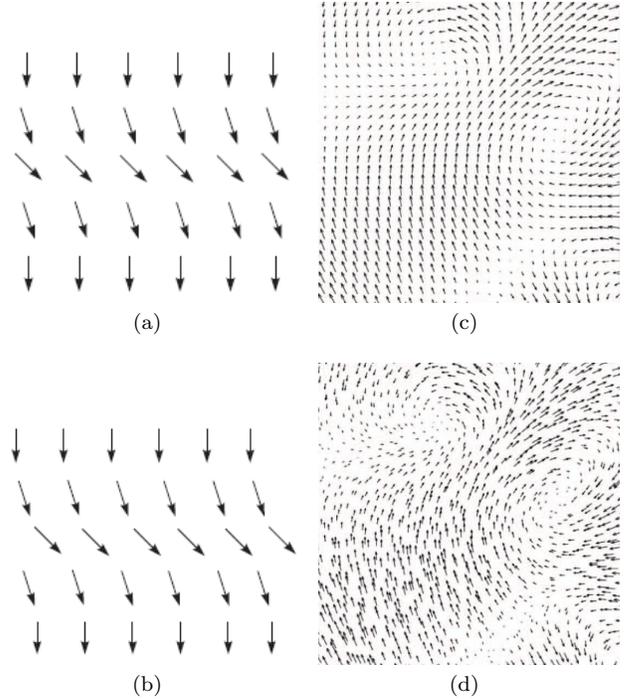


Figure 5: The arrows are aligned (a) on a grid (b) continuously with respect to the direction [Ware 2004]. Vector field visualization using a (c) grid (d) jittered grid [Laidlaw et al. 2005].

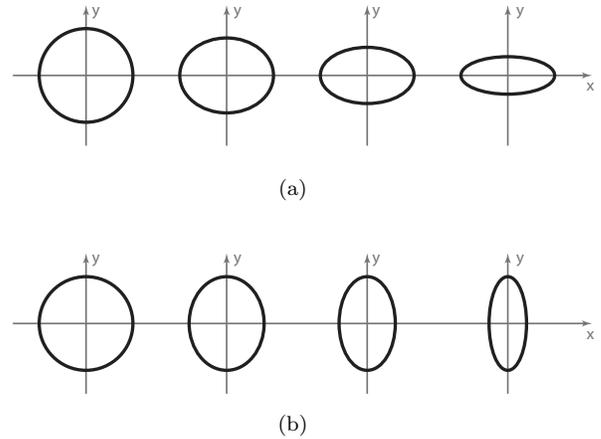


Figure 6: Elliptical Quadrics with parameters mapped to the axis in (a)  $y$ - and (b)  $x$ -direction. If the ellipses are rotated, only one of the above shown parameter mappings can be used, because the shape does not indicate which axis is manipulated (the lower row can be interpreted as  $90^\circ$  rotation of the upper row).

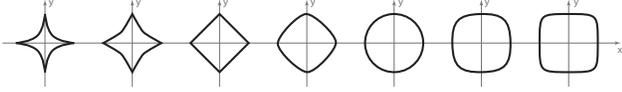


Figure 7: 2D-Superellipse given by Equation 3. The parameter  $n$  is varied from 0.2 to 4 from the left to the right shape. Parameters can be mapped to  $n$  and onto the axis ( $A, B$ ) of the shape as can be done with Quadric shapes.

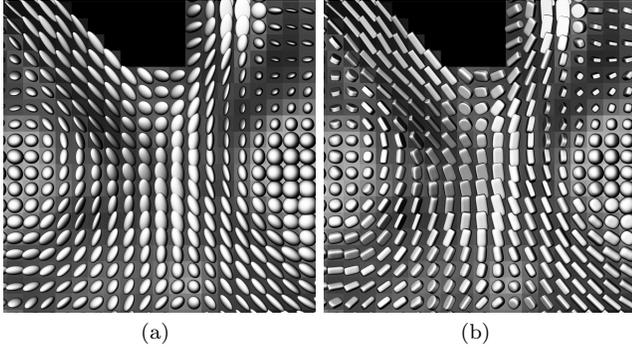


Figure 8: The same data visualized with (a) ellipsoids and (b) superellipsoids. Some of the ellipsoid shapes representing different data-mappings are hardly distinguishable. The superellipsoids are more distinct in this cases [Kindlmann 2004].

### 3.3 Superquadrics

An extension of Quadrics are the so called Superquadrics introduced by Barr [1981]. The general equation for Superquadric shapes is given in Equation 2.

$$\left| \frac{x}{A} \right|^p + \left| \frac{y}{B} \right|^q + \left| \frac{z}{C} \right|^r \leq 1 \quad (2)$$

Therefore six parameters ( $A, B, C, p, q, r$ ) can be mapped onto a Superquadric shape. The superellipses is given by Equation 3 and is presented in Figure 7. For this Figure the parameter  $n$  is varied from 0.2 to 4 and the parameters  $A$  and  $B$  are both set to 1. The 3D superellipsoid is given by Equation 4.

$$\left| \frac{x}{A} \right|^n + \left| \frac{y}{B} \right|^n = 1 \quad (3)$$

$$\left( \left| \frac{x}{A} \right|^n + \left| \frac{y}{B} \right|^n \right)^{\frac{q}{n}} + \left| \frac{z}{C} \right|^q \leq 1 \quad (4)$$

For glyph representations the parameters  $A, B, C$  are most commonly set to 1 and only  $p, q, r$  are used for the parameter mapping. Due to this the same amount of parameters as normal Quadrics can be mapped to a Superquadric. The advantage of Superquadric shapes is that their orientation is more distinguishable in comparison to Quadrics. This can be seen in Figure 8 where the same data is represented with ellipsoids (a) and superellipsoids (b). The problem of the ellipsoids is that some shapes can only be distinguished by the shading whereas the superquadrics have distinct shapes.

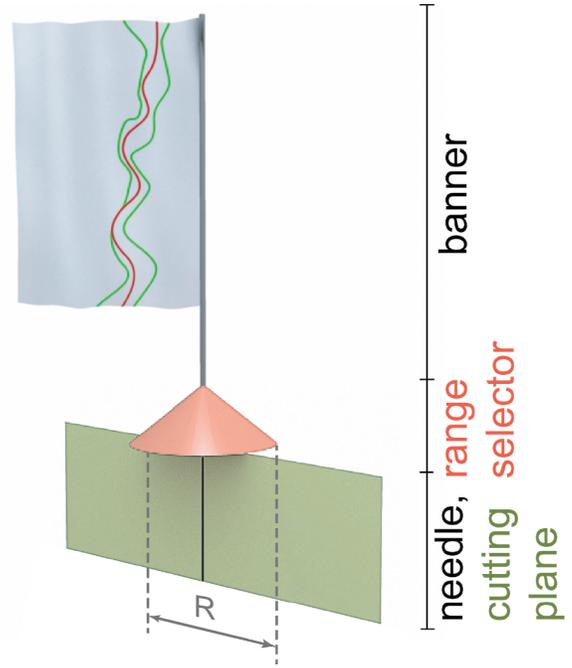


Figure 9: Concept art of a profile flag. The flag is oriented normally to the investigated surface. The main parts are the banner, range selector (with a region  $R$ ), needle and the cutting plane [Mlejnek et al. 2005].

### 3.4 Profile Flag

Thus far different basic glyphs have been discussed. Profile flags are composed of different parts and consequently are composite glyphs. They were introduced by Mlejnek et al. [2005].

The idea of the profile flag is to design a pin-needle like tool to investigate additional data which is selected through positioning the profile flag in the 3-dimensional environment. To get a better understanding of what a profile flag looks like, see Figure 9. Each flag consists of four main parts: banner, range selector, needle and cutting plane.

**Needle:** The needle which is directly connected to the flag-pole sticks into the surface and marks the position of the reference profile to be displayed on the flag. Two types of needles are described by Mlejnek et al. [2005] one with a fixed length and equidistant sampling of the underlying data. And an adaptive needle, which automatically changes the size.

**Range Selector:** In many cases it is important to get an overview of the data around a specific point. With the range selector the user gets a tool to individually set a range  $R$  in which the data is somehow aggregated to be imaged on the banner (see Figure 9).

**Banner:** The banner of a profile flag displays the underlying data of the selected position. The representation of the data has to be appropriate to the given task. In addition there could be several ways to present the data which can be switched through by the user investigating or annotating the data set. Mlejnek et al. [2005] presented four different ways to represent the data on the banner: **single profile** ( $R = 0$ ), **single averaged** profile (range  $R > 0$ , shows one

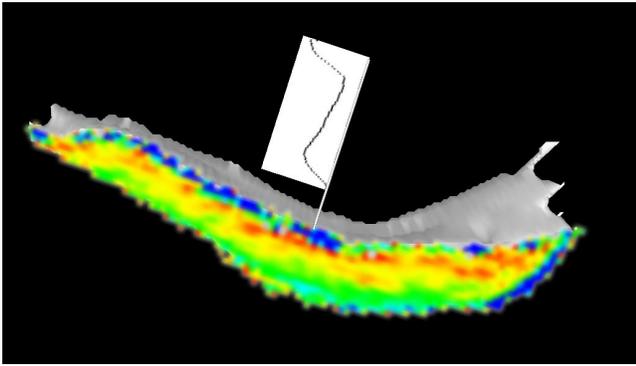


Figure 10: Cut through the reconstructed surface of an articular cartilage at the profile flag position. [Mlejnek et al. 2005].

profile which is the average of the neighborhood), **multiple profile** (range  $R > 0$ , the maximum and minimum value of all profiles in the neighborhood are additionally shown) and the **deviation profile** banner ( $R > 0$ , shows the difference of the neighboring profiles within the range to the reference profile marked through the needle).

**Cutting plane:** To analyze the data around the profile flag more precisely the cutting plane through the needle point can be displayed. This can be seen as a cut through the 3D data which is investigated. The cut can be used to visualize extra information extracted from the additional data set. Such a cut is shown in Figure 10. If the cut is displayed the user can rotate around the needle, or around the cut for detailed analysis.

The profile flag glyph is very intuitive and can be used with a low learning curve. The possibility of annotating data for later use or further analysis is a promising feature which could be thought of in different fields of visualization. To combine 2D and 3D information multiview visualizations techniques are presented in different ways. These multiview techniques have several windows which are interconnected. Due to this connection the presented information changes in all windows if the user selects a different data point to be inspected. A problem is that the spatial position of the data is only given through the combination of all open views. The profile flag combines the 3D position and the 2D information which conveys the spatial position.

If many profile flags are used to annotate a whole data set occlusions between the banners could occur. One has to think about solutions of how to handle such occlusions mainly if many profile flags are placed in a small region.

### 3.5 Star Glyphs

Star glyphs first mentioned by Siegel et al. [1972] are used to plot the  $M$ -tuple of an  $N$ -dimensional multivariate data as a star like glyph. Each glyph consists of  $M$  crossing rays (lines) and the angle between all these lines are uniformly separated. The length of each ray represents the magnitude of one value of the multivariate data set. Each star glyph can only represent one attribute (dimension) of the  $N$  dimensional data set. As an example only miles or weights can be represented by a star glyph if the data set in Table 1

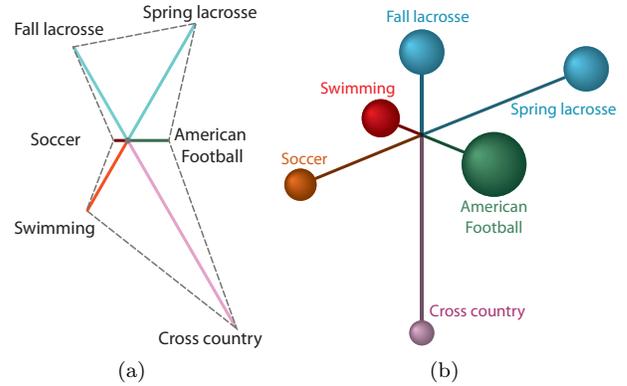


Figure 11: Star glyph representation using the data from Table 1. (a) as presented by Siegel et al. [1972] (only the Miles attribute is presented), (b) 3-dimensional star glyph with additional weight data as spheres [Rusu et al. 2009].

Table 1: Sample data used for Figure 11 [Rusu et al. 2009].

Sport	Miles	Weight	Color
American football	1.5	250	Green
Cross country	8	130	Purple
American soccer	4	160	Red
Swimming	0.5	140	Orange
Fall lacrosse	3	150	Magenta
Spring lacrosse	5	150	Magenta

is used. In Figure 11 (a) a simple star glyph using the data of Table 1 is presented.

To perceive the shape of each star glyph faster (if many glyphs are plotted at once) the ends of all rays are connected through a line [Siegel et al. 1972]. Figure 11 (a) shows such a star glyph. Newer versions of the glyph, as presented by Rusu et al. [2009], make use of the third dimension to make it easier to investigate data sets by rotating around the star glyphs, see Figure 11 (b) using the data of Table 1. Additionally, they added spheres at the end of each “data ray”, which represents a second attribute of the data set. The magnitude of this second attribute is mapped to the size of each sphere. For the reason of clarity the lines connecting the ends of the rays are omitted in this representation. By clicking on the spheres the user can receive more details of a specific data set. Also labels which can be turned on and off, to avoid cluttering if many star glyphs are rendered at one time, are provided.

## 4 Fields of Application

In this section some applications are outlined that make use of the different glyph designs mentioned previously.

The visualization of tensor data is addressed in different scientific disciplines. This leads to tensor data for medical applications like Magnetic Resonance Imaging (MRI) diffusion or strain tensors. Material science and geomechanics analyze stress and strain tensor fields as they are measured during earthquakes or material deformation. When fluid dynamics are analyzed, different properties can be expressed

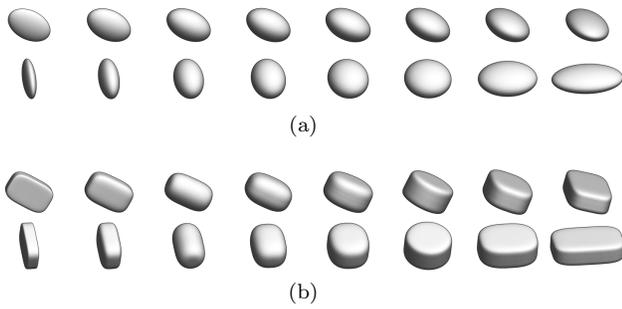


Figure 12: Tensor data visualization using (a) ellipsoids and (b) superquadrics. The first and second line of glyphs represent the same eight tensors from two different viewpoints [Kindlmann 2004].

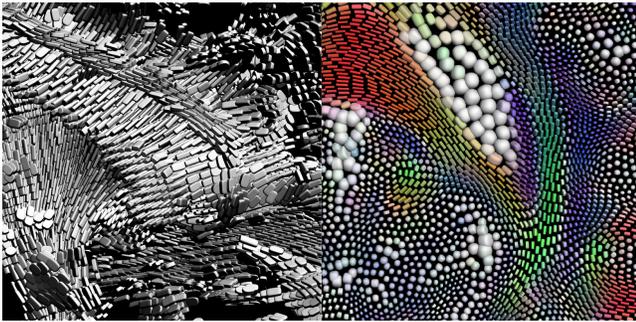


Figure 13: Superquadric glyphs used to visualize diffusion tensor data of the brain. Left: Method presented by Kindlmann [2004] and Right: an extension to this method using advanced glyph packing [2006].

with tensor data [Bürger and Hauser 2007]. Further information on second and higher order tensor data is given by Kriz [1995] and Wünsche [1999].

Often quadric or superquadric shapes are used to visualize tensor data. These shapes are capable of representing eigenvectors and -values extracted from the tensor data. If ellipsoids are used to visualize tensor fields, the absence of edges can cause problems such that the shapes are misleading. This problem can be seen in Figure 12 (a), where the first and second row represent the same tensors. Only the viewing direction is changed between the two lines of shapes, but different tensors have nearly the same appearance. This shortcoming was attributed by Kindlmann [2004] and leads to a design of Superquadric glyphs. In Figure 12 the elliptical (a) and superquadric (b) shapes of the same diffusion tensor data are shown to identify the stated problem of the ellipsoids.

Figure 13 shows a diffusion tensor visualization of medical data using superquadric glyphs (left side). The right image shows a slice of Diffusion-Tensor-MRI (DT-MRI) data with further improvements done to the glyph packing such that a better overview of the structural information can be perceived. Another combined visualization of superquadric glyphs and rendering of the underlying data is presented in Figure 14.

The profile flag can be used if one wants to combine different data sets in one visualization. Mlejnek et al. [2005]

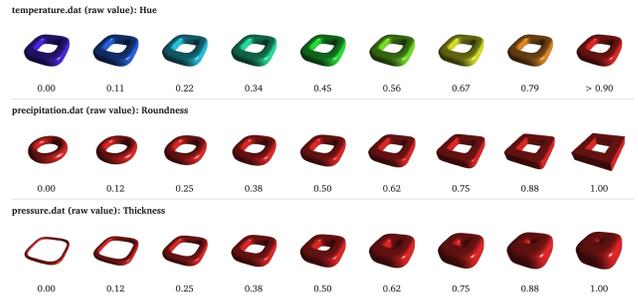
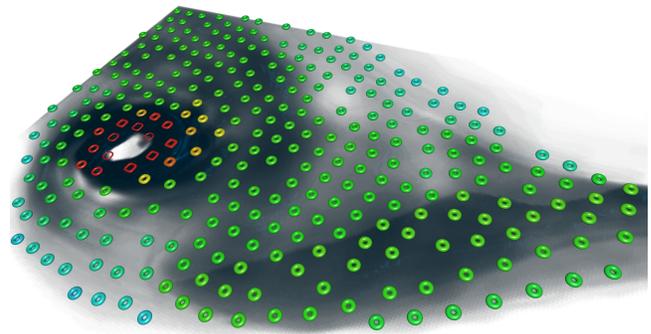


Figure 14: Superquadric glyphs are used to visualize a data set of the hurricane Isabel. A legend at the bottom helps to understand the mapping of the data to the superquadric shapes [Ropinski et al. 2007].

presented the profile flag for probing anatomical scans and their corresponding  $T_2$  maps of the cartilage. The  $T_2$  map is calculated from a series of spin-echo images with varying echo times acquired during the MRI. Radiologists use the anatomical scans and  $T_2$  maps to find possible degeneration or other diseases of knee cartilage. The profile flag can be used to avoid the presentation of these two data sets in different windows (or screens). This is done by visualizing the anatomical scan as a reconstructed surface. Profile flags can be further used to investigate suspicious areas and show the according  $T_2$  map of this area (see Figure 15). Research in the area of automated annotation of “abnormal” regions has been conducted. A problem of this automated annotation arises with occluding profile flags if too many regions of interest are found. The overview is lost in such a case which can result in suspicious regions not being analyzed properly. Additionally, the automated selection is always defective and should only be provided if the algorithms are reliable. By now the profile flag has only been used in medical visualization, but the area of applications is not restricted to this field.

Another composite glyph is the star glyph. Rusu et al. [2009] presented this type of glyph to compare different Trajectory Prediction (TP) Systems as they are used by the American National Airspace System. Trajectory Prediction assists the air traffic controller to plan the different trajectories of airplanes in such a way that the TP tries to predict the trajectory of the airplanes actually flying. If trajectories are conflicting the air traffic controller has to redirect the planes. The star glyphs are used to analyze the accuracy of the TP Systems. In Figure 16 an example is given. Three TP Systems are visualized with star glyphs. Each color represents a different aircraft type that is predicted and the length of the

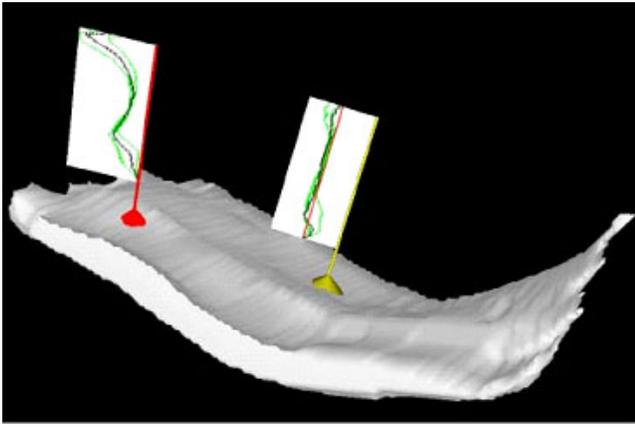


Figure 15: Two profile flags used to annotate regions of interest [Mlejnek 2006].

rays are the errors of this prediction. The size of the sphere at the end of the rays illustrates how many measurements were available to calculate the error between the prediction and the real trajectories. One can see that the URET (User Request Evaluation Tool) and ERAM (En Route Automation Modernization) TP Systems perform better than the Linear Predictor. A problem arises with the ERAM System and the blue aircraft type. The predictions for this aircraft type are not very accurate and the system can be improved to perform better.

## 5 Discussion

In the previous sections different glyph types and fields of applications are explained, but there are not only differences between the glyphs. In this section we will discuss common properties of glyphs and give usage guidelines.

One can use discrete or continuous parameter mapping functions. A linear continuous mapping function is most commonly used, see Figure 17 (a). Instead of this also a discrete (discontinuous) mapping function is possible, see Figure 17 (b) and (c). Figure 17 presents different mappings to the size of a glyph, but the different techniques for parameter mapping are not restricted by the size. The color and every other attribute can be mapped in many different ways. Discrete mappings can be more challenging to be perceived correctly, if not only step functions are used, see Figure 17 (b) and (c).

As mentioned before, color is an attribute that can be used for parameter mapping. Glyphs can be extended to have specific color mappings. Color is a good preattentive feature to detect regions of interest (regions of interest have to be defined by the given problem). Therefore, color can be used to present an overview of an important value of the data set (like highlighting maxima and minima), which can be seen in Figure 14. If the user wants to further inspect a certain region, other properties should be used to visualize the differences because the human visual system is not accurate in detecting smooth color changes.

An extension to color mappings can be the use of transparency. The transparency of glyphs can easily highlight

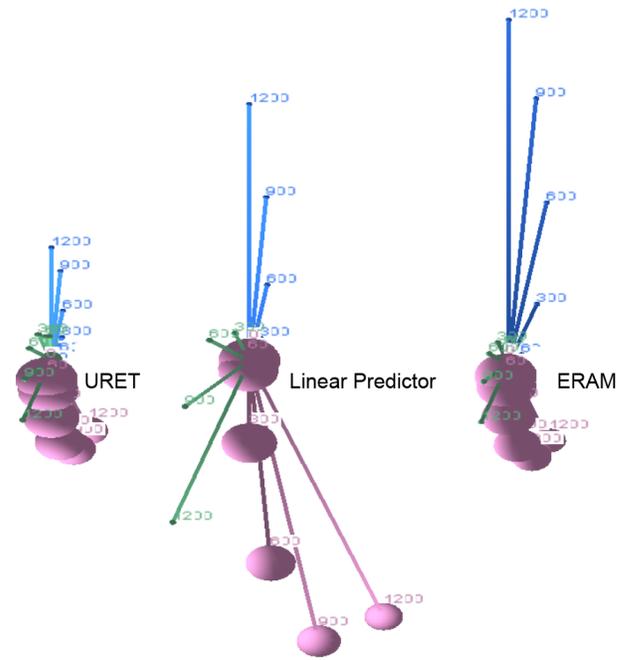


Figure 16: Star glyphs of three different trajectory prediction systems. The length of the ray represents the error during the prediction and different colors are used for different aircraft. The size of the sphere indicate the count of measurements used for the visualization and the numbers are the prediction times in seconds [Rusu et al. 2009].

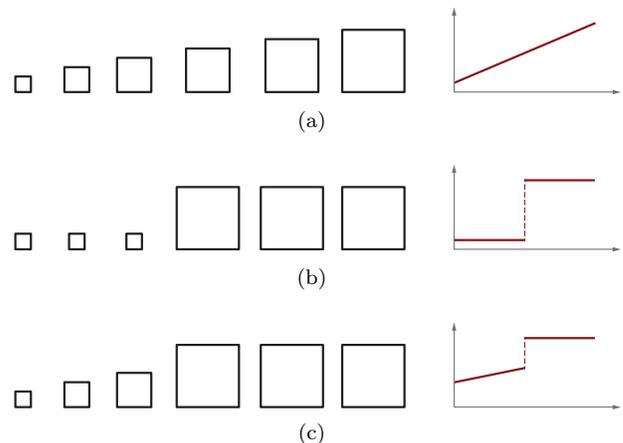


Figure 17: Different mappings of the size (left) and the according mapping function (right). The mapping (a) is a continuous mapping and (b)(c) are two discrete ones.

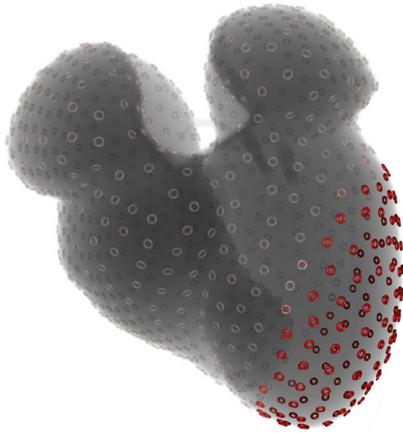


Figure 18: PET/CT x-ray scan of the heart. The cardiac wall motion and activity is represented through glyphs. More opaque glyphs indicate higher motion.



Figure 20: Feature-driven glyph placement using the normal vector of the skull surface [Ropinski et al. 2011].

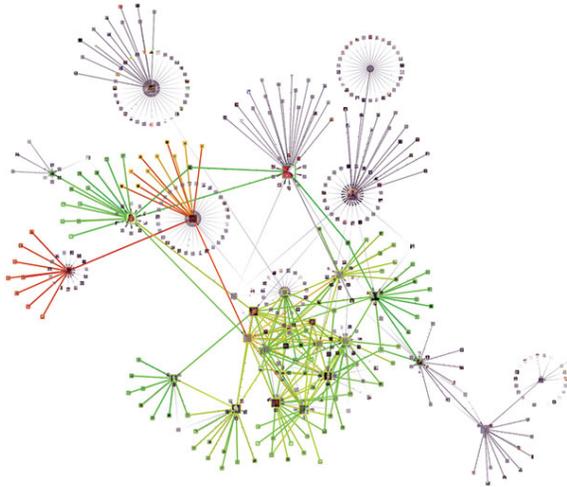


Figure 19: Structure-driven glyph placement of the message passing within a social network [Offenhuber and Donath 2007].

certain regions and is a good preattentive stimulus in combination with a color coding. The mapping has to be handled carefully, because the user cannot investigate regions of high transparency and glyphs can disappear completely. The effect of disappearing glyphs can be used to remove unwanted or unreliable data points, but one has to be aware of the fact. In Figure 18 the Positron Emission Tomography (PET)/CT x-ray scan of a heart is visualized. The transparency of the glyphs shows the cardiac wall motion and activity (high motion is in areas of opaque glyphs) [Ropinski et al. 2007].

Not only the visual appearance of glyph shapes is important for a good representation of the data. The placement of the glyphs within space must also be considered. Ward [2002] presented a taxonomy on different glyph placement strategies. The two main strategies described by Ward are the data-driven and structure-driven glyph placement. Ropinski and Preim [2008] extended this taxonomy for medical visualization. They added data set-driven and feature-driven

glyph placement to the taxonomy. Data-driven placement directly maps one or more dimensions of the data set to spatial positions of the glyph. Another data-driven method generates the placement of the glyphs based on the analysis of all (many) dimensions of the given data set (e.g. Principal Component Analysis (PCA), Multidimensional Scaling (MDS) or simulated annealing). Structure-driven placement analyzes the relationship between different data-points within a data set. A simple example would be the placement of different nodes of a graph representing users of a social networking platform. The nodes are connected according to the messages passed between “friends” using this platform, see Figure 19 [Offenhuber and Donath 2007]. Data set-driven placement strategies make use of predefined grid like structures to place the glyphs. This grid can be regular or in some way jittered as it is described by Laidlaw et al. [1998]. As well other grid like strategies can be used to place the glyphs. Feature-driven placement uses features derived from the given data set to place the glyphs. The glyphs are, for example, oriented on the basis of the surface normal and placed on the surface itself, see Figure 20.

All these placement strategies have to consider occlusions and aggregations of glyphs. A sophisticated glyph placement strategy for medical visualization is presented by Kindlmann and Westin [2006] and can be seen in Figure 13 on the right side. Another concept in glyph placement is to allow the movement of glyphs within the visualization. Therefore the user can investigate the whole data set by moving the glyphs around. The profile flag is an example of this type of placement.

An extension to all these glyph placements can be the animation over time, if the data set is time dependent. Animations of glyphs can be very helpful for users in understanding changes over time. Different controls for the modification of the animation like stopping, changing the speed, or pausing, must be provided.

The mentioned properties can be summarized in usage guidelines for glyph visualization. Ropinski and Preim [2008] proposed such usage guidelines for medical glyph visualization purposes, but they are valid for more generalized glyph visualizations as well.

These guidelines are extended in later work [Ropinski et al. 2011] and are defined as follows:

1. Parameter mapping functions should
  - Visually emphasize important variables.
  - Incorporate the range of values.
  - Guide the users focus of attention to encode relevance.
  - Incorporate semantics of the data.
  - Be mentally reconstructable based on the visualization.
2. Glyph placement should be well-balanced and avoid unwanted glyph aggregations in image space, e.g., by applying jittering or relaxation procedures.
3. Glyph shapes should be unambiguously perceivable independent of the viewing direction.
4. Glyph visualizations should support quantitative analysis in the attentive phase.
5. Hybrid visualization should be exploited to provide the anatomical context.
6. When using the glyph size to convey information, perspective projections should be avoided.

As can be seen the main focus of the guidelines is the parameter mapping, which is a crucial step during the design of meaningful glyphs. The fifth guideline can be formulated more broadly as “Hybrid visualizations should be exploited to provide the spatial context” [Ropinski et al. 2007]. This guideline should be given more focus if glyph visualizations are used, because hybrid visualizations are more meaningful. The reason for this is that the user can perceive the spatial context from an underlying visualization, whereas a lot of glyphs can not deliver this information. In Information Visualizations no spatial data is available, therefore this guideline can be ignored. Overall, these guidelines can help to rethink a designed glyph and can adjust some parameter mappings to create better glyph visualizations.

## 6 Conclusion

In this paper different glyph visualization techniques have been presented. Various kinds of glyphs were classified into basic and composite glyphs, where composite glyphs are built out of basic shapes. To create meaningful glyph visualizations, preattentive and attentive stimuli can be used to support the user. Different features can be preattentively processed and this should give an overview of the data set. Further investigations make use of attentive processing and methods like a glyph legend can help the user during this step. Usage guidelines have been presented and discussed as they are given in the literature [Ropinski and Preim 2008]. Such guidelines can be helpful during the design of new glyphs.

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