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Glyph-Based Multifield Visualization

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Abstract

1 Introduction

The visualization of data that are given as fields of values is a classical topic in visualization research. A substantial amount of relevant work has been done, offering a wealth of well-proven techniques for revealing insight into such data fields. When visualizing multiple fields of data that co-exist with respect to a joint domain of reference, additional challenges are faced. One the one hand, there is a *technological challenge* of how to realize a visualization mapping that can reveal multiple fields of data at a time. On the other hand, there is a *perceptual challenge* of how easy it is to understand and correctly interpret such a visualization.

Glyph-based visualization is one possible approach to realize such a visualization of multi-field data (and other chapters of this book part describe alternative approaches). A parameterized visualization object is considered – called a *glyph* (or sometimes also an icon) – such that certain specifics with respect to its form, e.g., its shape, color, size/orientation, texture, etc., are given according to data values which this glyph should represent. A glyph-based visualization is then created by arranging a certain number of these glyphs across the domain of reference (these could be just a few, or just one, or many, even so many that they merge into a dense visual-

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ization) such that every glyph becomes a visualization of the data at (or nearby) the location where the glyph is placed.

Glyph-based visualization approaches span a certain spectrum from, for example, dense arrangements of relatively simple shapes (stick figures would be an example) to individual instances of complex glyphs that reveal a lot of information (but only for few, selected places) – the local flow probe would be an example for this type of a glyph-based data visualization. Glyph-based visualization approach also vary with respect to whether they are constructed in a 2D or 3D visualization space. We think that it also makes sense to consider glyph-based visualization approaches, which are based on the placement of glyphs on surfaces within 3D (called 2.5D in the following). Additionally, we can differentiate visualization solutions according to which form aspects are varied according to the data, and how many different values a glyph eventually represents (usually this number is not too large, often 2 to 4, but then also examples exist where dozens of values are represented).

A property of all glyph-based visualization approaches is that a discrete visualization is created (instead of a continuous representation like a color map) – only at certain locations across the domain individual glyphs are instantiated to represent the data. This means that this approach is only suitable, when it is possible to assume a certain minimal degree of continuity of the data such that a mental reconstruction of the data, in particular also in the space between the glyphs, is at least principally possible. In scientific visualization, this often is possible, making glyph-based visualization particularly interesting for this particular field of application. Alternatively, a glyph-based visualization also makes sense for discrete data, if a one-to-one relation between every instance of the data and the glyphs is established.

In the following, we first review a selection of techniques that have been proposed for glyph-based data visualization. Then, we continue with a discussion of critical design aspects of glyph-based visualization, not at the least oriented at opportunities to deal with the perceptual challenge that is inherently associated with this form of visualization approach.

2 State-of-the-Art

This section presents a selection of important papers with a focus on glyph-based multifield visualization. A categorization is given based on the visual channels such as color, shape, size, texture and opacity occupied by the glyph in requirement for mapping each data attribute. We further cluster the techniques in respect to the spatial dimensionality of the visualization e.g., 2D, 2.5D and 3D. Texture can be subjective in terms of glyph-based classification, however we find that it is very relevant in the research of multifield. The following work can be acknowledged without the use of this classification, but we include this in the table for completeness.

Superquadrics and Angle-Preserving Transformations by A. H. Barr [Bar81] introduces geometric shapes (superquadrics) to be used for creating and simulating

Visual Channel	Visualization Dimensionality 2D	2.5D	3D
Color	[HBE96] [KML99] [Tay02]	[CA91] [HE99] [PGL+11]	[SEK+98] [KE01] [Kin04] citechlan05 [KW06] [MSSD+08] [KMDH11]
Shape	[KMDH11]		[Bar81] [dLvW93] [SEK+98] [Kin04] [JKM06] [KW06] [MSSD+08]
Size	[WPL96] [Tay02] [SZD+10]	[CA91] [PGL+11]	[SEK+98] [Kin04] [CR05] [MSSD+08]
Texture	[Tay02]	[CA91] [HE99]	
Opacity	[KML99] [Tay02]		[MSSD+08]

Table 1 Table illustrating a classification of multi-variate glyph-based visualization techniques based on the visualization dimensionality and the visual channels required to depict the data set.

three-dimensional scenes. The latter part provides shape transformations that preserve angles. The author defines a mathematical framework used to explicitly define a family of geometric primitives from which their position, size, and surface curvature can be altered by modifying a family of different parameters. Example glyphs include: a torus, star-shape, ellipsoid, hyperboloid, toroid. The paper then goes on to describe shape transformation matrices that can be applied to primitives to create the following effects: bending or twisting, whilst preserving their angles.

A Scientific Visualization Synthesizer by R. A. Crawfis and M. J. Allison [CA91] introduces a novel approach for visualizing multiple scientific data sets using texture mapping and raster operations. The authors present an interactive programming framework that enables users to overlay different data sets by defining raster functions/operations. Using a generated synthetic data, the author presents a method for reducing the visual clutter by mapping color to a height field and using a bump map to represent the vector plots and contour plots. The final texture is mapped onto 3D surface.

Data Visualization Using Automatic, Perceptually-Motivated Shapes by C. Shaw et al [SEK+98] describes an interactive glyph-based framework for visualizing multi-dimensional data through the use of superquadrics. The author uses the set of superquadrics defined by Barr [Bar81] and describes a method for mapping data attributes appropriately to shape properties such that visual cues effectively convey data dimensionality without depreciating the cognition of global data patterns. They map in decreasing order of data importance, values to location, size, color and shape (of which two dimensions are encoded by shape). Using superellipsoids as an example, the authors applied their framework to the following data sets: "thematic" document similarities [SEK+98] and a magnetohydrodynamics simulation of the solar wind in the distant heliosphere [E+00], [ES01].

Visualizing Multivalued Data from 2D Incompressible Flows Using Concepts from Painting by R. M. Kirby et al [KML99] presents a novel visualization method for displaying multiple data values from a 2D flow on an image for simultaneous observation. The authors present a user-specified framework for visualizing multiple data values by mapping each data set to layers on an image. Layers are given an emphasis value of increasing weights in a bottom to top fashion such that the lowest layer has the least emphasis and the highest layer the most. Visual cues such as color and opacity are used indicate regions and layers of importance (e.g., Rate of strain tensor example emphasized the velocity more by using black arrows). This method enables a visual display of 6-9 data attributes simultaneously. The authors apply this technique to a simulated 2D flow past a cylinder at different reynolds number, where they visualize the velocity, vorticity, rate of strain tensor, turbulent charge and turbulent current.

Visualizing Multiple Fields on the Same Surface by R. Taylor [Tay02] provides an overview of successful and unsuccessful techniques for visualizing multiple scalar fields on the same surface. The author first hypothesizes that the largest number of data sets that can be displayed by mapping each field to the following: a unique surface characteristic, applying a different visualization technique to each scalar field or by using textures/glyphs whose features depend on the data sets. This framework is limited to visualizing up to four scalar fields. The author then describes two techniques that prove effective for visualizing multiple scalar fields, (1) *data-driven spots (DDS)* - using different spots of various intensities and heights to visualize each data set, and (2) *oriented slivers* - using sliver like glyphs of different orientations that are unique to each data set along with various blending.

Superquadric Tensor Glyphs by G. Kindlmann [Kin04] introduces a novel approach of visualizing tensor fields using superquadric glyphs. Superquadric tensor glyphs address the problems of asymmetry and ambiguity prone in previous techniques (e.g. cuboids and ellipsoids). The author provides an explicit and implicit parameterization of the primitives defined by Barr [Bar81] along with geometric anisotropy metrics c_l, c_p, c_s and user-controlled edge sharpness parameter γ, to create a barycentric triangular domain of shapes that change in shape, flatness and orientation under different parameter values. A subset of the family of superquadrics is chosen and applied towards visualizing a DT-MRI tensor field which is then compared against an equivalent ellipsoid visualization.

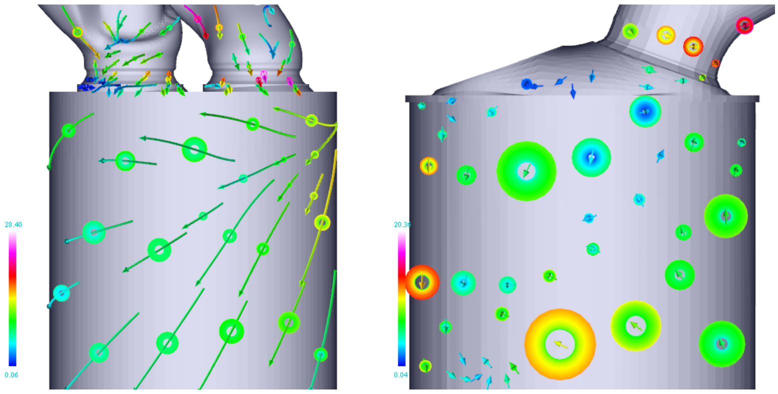

Fig. 1 Visualization of the flow in an engine using composite glyphs that depict the range of vector magnitude and direction in each cluster by Peng *et al.* [PGL+11]

Mesh-Driven Vector Field Clustering and Visualization: An Image-Based Approach by Z. Peng et al [PGL+11] presents a novel approach for automatic vector field clustering and visualizing that incorporates statistical-based multi-variate glyphs. The authors clustering algorithm 1) derive a mesh resolution value for each vertex, 2) encode vector and mesh resolution values into R, G, B and α in image space. Clusters are formed in this image space. 3) the clusters are merged depending on a similarity value based on euclidean distance, mesh resolution, average velocity magnitude and velocity direction. A cluster visualization is illustrated using a $|v|$-range glyph that depicts the local minimum and maximum vector, and a θ-range glyph that shows the variance of vector field direction in addition to the average velocity direction and magnitude. Other visualization options include streamlets that are traced from the cluster centre, and color coding with mean velocity. The authors demonstrate their clustering results on a series of synthetic and complex, real-world CFD meshes.

3 Critical Design Aspects of Glyph-based Visualization

It was a wide-spread opinion for a long time that “just” knowing the basic principles of glyph-based visualization would suffice to its successful usage. More recently, however, it has been understood that only well designed glyphs, where different glyph properties are carefully chosen and combined, are actually useful. In this section, we discuss critical design aspects and guidelines for glyph-based visualization.

In the context of information visualization, Ward [War02] discusses glyph placement strategies such as data- or structure-driven placement. Ropinski and Preim [RP08] propose a perception-based glyph taxonomy for medical visualization. The authors categorize glyphs according to 1) preattentive visual stimuli such as glyph shape, color and placement, and 2) attentive visual processing, which is mainly related to the interactive exploration phase (e.g., changing the position or parameter mapping of a glyph). Additional usage guidelines are proposed, for instance, that parameter mappings should focus the user's attention and emphasize important variates in the visualization. Also, glyph shapes should be unambiguous when viewed from different viewing directions. Kindlmann [Kin04], for example, use superquadric glyph shapes that fulfill the latter criterion.

Inspired by the work of Ropinski and Preim, Lie et al. [LKH09] propose further guidelines for glyph-based 3D visualization. Aligned with the visualization pipeline [HS09], the task of creating a glyph-based 3D visualization is divided into three stages as shown in Fig. 2: 1) during *data mapping*, the data variates are remapped (to achieve, for example, some contrast enhancement) and mapped to the different glyph properties; 2) *glyph instantiation* creates the individual glyphs, properly arranged across the domain; and 3) during *rendering*, the glyphs are placed in the visualization, where one has to cope with issues such as visual cluttering or occlusion. In the following, we discuss critical design aspects for each of these steps.

Similar to Ward [War02], Lie et al. consider it useful that the glyphs expect normalized input from the depicted data variates such as values in the range $[0,1]$. During data mapping, the authors identify three consecutive steps. First, the data values within a user-selected range $[w_{left}, w_{right}]$ are mapped to the unit interval. Values outside this range are clamped to 0 or 1, respectively. This allows to enhance the contrast of the visualization with respect to a range of interest (sometimes called windowing). A natural default choice for this step would be a linear map between $[w_{left}, w_{right}]$ and $[0,1]$, but also other forms of mapping could be considered (for example, a ranking-based or discontinuous mapping). After the windowing, an optional exponential mapping $e(x) = x^{\gamma}$ can be applied in order to further enhance the contrast on the one or the other end of the spectrum. Finally, a third mapping step enables the user to restrict or transform the output range that should be depicted by a glyph property. Here, also semantics of the data variates can be considered (compare to the usage guidelines of Ropinski and Preim [RP08]). Using a reverse mapping, for instance, smaller data values that are possibly more important can be represented in an enhanced style while larger values are deemphasized.

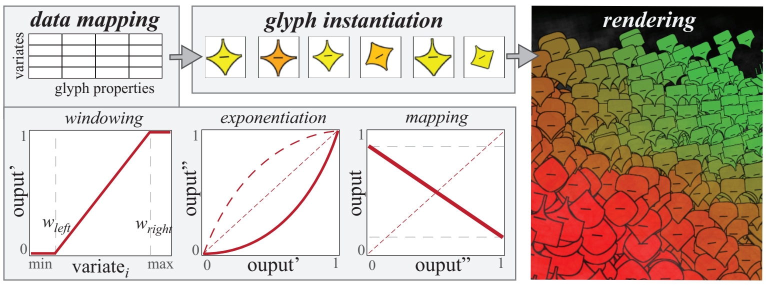

Fig. 2 Each data variate is subject to three stages of data mapping: windowing, exponentiation and mapping. The values are mapped **[anyone a better word?]** to different glyph properties and used to instantiate the individual glyphs. Finally, the glyphs are rendered in their spatial context.

Several considerations are important for the instantiation of individual glyphs. When using a 3D glyph shape, one has to account for possible distortions introduced when viewing the glyph from a different point of view [Kin04]. In order to avoid this problem, Lie et al. suggest to use 2D billboard glyphs instead.[1] In certain scenarios, however, it makes sense to use 3D glyphs, for example, when depicting a flow field via arrow glyphs. Another challenge in glyph design is the *orthogonality* of the different glyph components, meaning that it should be possible to perceive each visual cue individually (or to mentally reconstruct them as suggested by Preim and Ropinski [RP08]). When representing a data variate by glyph shape, for example, this affects the area (size) of the glyph as well. Accordingly, such effects should be *normalized* against each other, for instance, by altering the overall glyph size in order to compensate for implicitly changes of the glyph shape.

However, it is not always easy to design a glyph-based visualization such that the different data-to-property mappings are independent and do not influence each other (the interpretation of shape details, for example, is usually influenced by the size of the glyph). In this context, the number of data variates that can be depicted must be seen in relation to the available screen resolution. Large and complex glyphs such as the local probe [dLvW93] can be used when only a few data points need to be visualized. If many glyphs should be displayed in a dense manner, however, a more simple glyph may be desirable [KW06]. Another design guideline is the usage of *redundancies*, for instance, to use symmetries that ease the reconstruction of occluded parts of the glyph. Important properties can, moreover, be mapped to multiple glyph properties in order to reduce the risk of information loss.

Important aspects when rendering many glyphs in a dense 3D context are depth perception, occlusion, and visual cluttering. In cases where many glyphs overlap, *halos* can help to enhance the depth perception and to distinguish individual glyphs (compare to Piringer et al. [PKH04]). For improving the depth perception for non-overlapping glyphs a special color map (called *chroma depth* [Tou97]) can be used to represent depth. Finally, appropriate glyph placement [RP08, War02], interactive slicing, or filtering via brushing are strategies for dealing with occlusion and cluttering issues.

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[1] A billboard is a planar structure placed in a 3D scene, which automatically adjusts its orientation such that it always faces the observer.

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