SMOOTH BRUSHING FOR FOCUS+CONTEXT VISUALIZATION OF SIMULATION DATA IN 3D

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ABSTRACT

We present the usage of a non-discrete degree of interest (DOI) function, obtained by brushing multi-valued 3D simulation data in information visualization views, to define opacity, color, and geometrical transfer functions for 3D rendering in a scientific visualization view via linking. To reflect the smooth nature of features in flow simulation data, smooth brushing was chosen. Different available views and interaction methods of a prototype system are discussed, and examples from 3D flow simulation are shown.

Keywords: F+C Visualization, Linking & Brushing, Information Visualization, Scientific Visualization, 3D Visualization, Transfer Function Modulation, Flow Simulation

1 INTRODUCTION

In this paper we present a new solution for feature-based visualization, which is especially useful for analysis or exploration of simulation data. In our case, the data comes from flow simulation in automotive applications. We are dealing with multi-dimensional and multi-modal data-sets from flow simulation, which are layed out on unstructured grids in two or three spatial dimensions.

In general, simulation data often exhibits a rather smooth distribution of data values along spatial dimensions. This requires special treatment when dealing with feature specification (see later about smooth brushing). As a special feature of the solution described here, a 3D visualization of the data is inherently integrated into our approach.

Dealing with occlusion in SciViz – when rendering truly three-dimensional information in scientific visualization (SciViz), such as, for example, medical data acquired from computer tomography, it is very important to decide *how* to render the data. But even more important, the question of *what* parts of the data should be displayed needs to be addressed [6]. Because of occlusion, not all of the data can be shown concurrently.

In volume rendering, usually a so-called *transfer function* is employed, which assigns an opacity value to each of the data items. A compositing procedure is used, featuring semi-transparency for image synthesis. The design of a transfer function is a difficult challenge, that strongly depends on the specific goals of the visualization process. At the IEEE Visualization conference in 2000, the most recognized approaches have been discussed in an interesting panel [8].

Separating focus & context in InfoViz – apart from SciViz as discussed above, information visualization (InfoViz) also deals with data-sets of tremendous size and increased dimensionality. Since the simultaneous display of all of the data items usually is impossible, *focus-plus-context* (F+C) techniques are often employed to show some parts of the data in detail, and at the same time the rest of the data as a context for orientation. This is especially useful when interacting with the data, or navigating through the display [2].

To discriminate data *in focus* from context information, a so-called *degree of interest* (DOI) function can be used [4]. It assigns to each of the n-dimensional data items a 1D DOI-value out of the unit interval (1 represents "in focus", 0 is used for context information).

Using a DOI function for opacity modulation – in this paper we demonstrate how the idea of F+C visualization and the use of a transfer function for volume rendering can be combined (through *linking*, a well-known concept from InfoViz, see below). To do so, we use a DOI function that is defined by interactive means on the n-dimensional domain of the simulation data. It is then used as a transfer function for opacity modulation. Thereby, a 3D F+C visualization of flow features is realized: parts of the data which are *in focus*, i.e., the flow features, are displayed rather opaque, whereas the rest of the data (the context) is shown translucent.

This means, that concentrating on features during visualization also allows to improve on the occlusion problem which is inherent to 3D rendering.

Smooth Brushing – for specifying the DOI function on the n-dimensional domain of simulation data, we use an interactive brushing tool which is based on separate InfoViz views. To cope with the rather smooth distribution of simulation data, we use so-called *smooth brushing* which results in a DOI function that continuously maps to the $[0, 1]$ range. The hereby derived DOI function also can be interpreted as a fuzzy set describing a "degree of being *in focus*" [15]. For scientific visualization, the DOI function, as specified in an InfoViz view, corresponds to modulated opacity values in 3D rendering (through linking).

2 RELATED WORK

As the work presented in this paper relates to several different areas of visualization research, this section consists of several parts. A short discussion of the most important approaches is given here, for more detailed information the reader is pointed to the indicated references.

Visualizing n-dimensional data from flow simulation – in general, simulation of flow data yields multiple values per data item such as, for example, pressure, temperature, and velocity. Visualization of all these different values is useful for understanding the results of the simulation, and for enabling the analysis process. Standard 2D solutions (color plots, graphs, etc.), as well as surface-based solutions embedded in 3D (iso-surfaces, for example) are widely available in commercial software products.

On top of standard solutions, Kirby et al. propose simultaneous visualization of multiple values (of 2D flow data) by using a layering concept related to the painting process of artists [9]. In another approach for 2D CFD data, called Linked Derived Spaces [7], Henze uses multiple 2D views (featuring geometrical connectivity), which are linked, and allow discrete brushing – opposed to *smooth* brushing as featured in our approach – in all of the views.

Another related topic is feature-based flow visualization, e.g., detection and visualization of vortices or vortex cores – recent work has been presented by Roth and Peikert [11] as well as Sadarjoen et al. [12].

Linking & Brushing for connecting SciViz & InfoViz – *linking & brushing* is a useful and well-appreciated concept, known from InfoViz. *Brushing* is a process in which the user can interactively highlight, select, or delete a subset of elements with regard to visualization by using some appropiate brushing tool. Often, brushing is associated with *linking*, a process in which brushing some elements in one view directly affects the visual appearance of the data in other (linked) views. Already in 1987, Becker and Cleveland applied linking & brushing to high-dimensional scatter-plots [1].

The principal idea of linking SciViz & InfoViz views has already been demonstrated in a system called WEAVE, by Gresh et al. [5]. In this approach, which deals with data from a heart simulation, (discrete) brushing is performed in InfoViz views – a 3D view is linked via through coloring. However, this system does not feature volumetric rendering based on semitransparency, only surface- and point-based methods are used. Also in the linked derived spaces [7] (see above) it is possible to show the two spatial dimensions of the grid in one of the scatter-plots for 2D scientific visualization.

DOI functions for discriminating Focus & Context – DOI functions (as described above) have been introduced by Furnas in 1986 [4]. Multiple ways of how to define a DOI function have been presented since then, using either explicit or implicit specification. Whereas many F+C solutions build on an explicit specification of the focus, e.g., by pointing at data item of specific interest, others use an implicit and data-driven specification of what is *in focus*. Examples are querying methods as, e.g., used in the XmdvTool [14].

Martin et al. [10] extended the usage of brushes to define a DOI function by several new concepts, including non-discrete brush-boundaries, simultaneous display of multiple (up to four) brushes, and creating composite brushes via logical operators.

3D rendering / dealing with occlusion / F+C solutions – when rendering 3D data with a volumetric approach, the problem of occlusion needs to be solved. In standard 3D rendering, the concept of using an opacity transfer function for this purpose has been well accepted in the field of scientific visualization [8]. A recent approach of volumetric flow rendering was Raycasting Vector Fields presented by Frühauf [3], which directly renders all of the available data elements, and therefore lacks easy spatial perception.

A similar problem of occlusion, due to a lot of data being shown, is apparent in information visualization – the input often comprising very large and high-dimensional data sets. Here the concept of *focus+context visualization* was established [2]. The basic idea of this concept is to enable users to have the object of primary interest presented in detail, while still preserving an overview or context available at the same time.

There are few attempts to utilize F+C solutions also in scientific visualization, one is two-level volume rendering [6], where different rendering techniques can be applied to different objects in a 3D data set, depending on whether they are in focus or not.

3 Focus+Context Visualization of Simulation Data Based on Smooth Features

Inspired by the work of Gresh et al. (WEAVE [5]), and two-level volume rendering [6], we found F+C visualization to be also very useful in scientific visualization. Both approaches use a different visual appearance for data *in focus* vs. the display of context information. In WEAVE, InfoViz views are used to specify data in focus, whereas in two-level volume rendering objects appear *in focus* through explicit selection. While WEAVE uses linked color coding for 3D F+C visualization, two-level volume rendering uses different techniques of (more or less) translucent 3D rendering for F+C display.

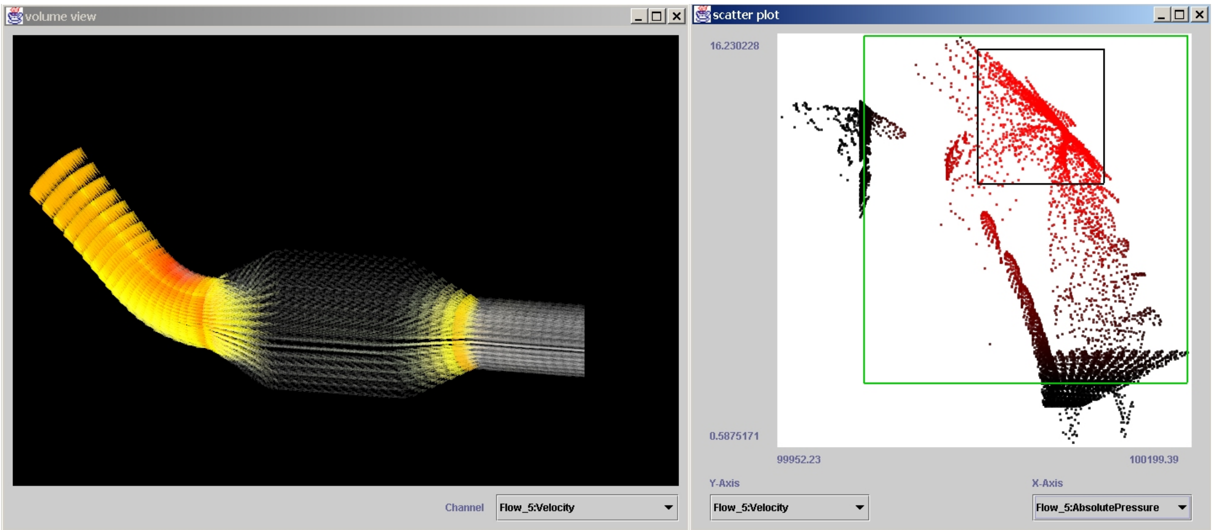


Figure 1: *Smooth Brushing and Linking:* simulation data of a catalytic converter is shown. Right side:a scatter-plot, where a non-binary DOI function was defined by smooth brushing a cluster of high velocity/high pressure data; Left side: a 3D SciViz view, employing opacity/color modulation for the 3D arrows.

We think that a F+C approach in scientific visualization fits together very well with the challenge of solving the occlusion problem in 3D rendering. F+C solutions in InfoViz and the notion of features in feature-based visualization correspond very well, as in both fields a level of interest is specified for special parts of the data. When dealing with 3D rendering of the data, occlusion is an inherent problem to tackle. It can be solved by modulating the opacity of data items in 3D rendering according to a degree of interest function.

Both from InfoViz and WEAVE, we know that the concept of linking & brushing is very useful for discriminating focus and context in visualization. In our approach we use InfoViz views on high-dimensional data from flow simulation to specify the desired DOI function interactively according to different attributes of the data items. This DOI function is linked to the 3D view, showing the features of interest in a F+C style.

As a speciality of data from flow simulation, data values are distributed rather smoothly along spatial dimensions. Different to data from medical visualization, for example, almost no sharp boundaries of (flow) features are given. To cope with this special type of data, we use a non-discrete brushing technique, which we call *smooth brushing*, to specify a continuous DOI function for F+C visualization.

For evaluation of our ideas, we implemented a software prototype that supports different views from SciViz & InfoViz together with smooth brushing in InfoViz views, as well as linking of the 3D view to InfoViz views through the continuous DOI function. In 3D rendering, DOI values influence the opacity of display elements, and/or their color coding, as well as their geometrical properties, e.g., their size.

Fig.1 gives an example of the solution described here, showing an application featuring data which comes from a 3D simulation of flow in a catalytic converter. The left view shows a scientific visualization with small 3D arrows representing data items. Velocity is mapped to color, with red corresponding to high velocity. The right view is a scatterplot where velocity values are plotted against values of static pressure. A non-binary DOI function was defined by smooth brushing a cluster of data items exhibiting high velocity and rather high pressure. This DOI function was used to modulate the opacity as well as the color of the 3D arrows in the rendering view – display elements not in focus are drawn in a gray-scale fashion. One can see that mainly the inlet of the catalytic converter (upper left part in the 3D view) exhibits values of high pressure and high velocity. Through the smooth brush parts of the outlet are also of partial interest, since values there are not much different to the core focus of this visualization, and thus are also partially influenced by the F+C mapping.

4 Views and Interaction

To test our ideas we implemented a prototype including the two most prominent InfoViz views (scatter-plot and histogram view) and a 3D rendering view with different representation modes.

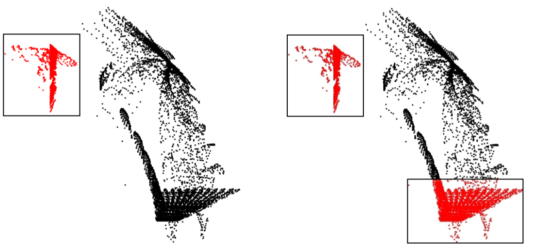
In the scatter-plot view the two attribute-to-axis mappings are interactively configurable, any attribute dimension available in the data set can be used on any of the two axes. Additional feedback is provided by showing zero-axes and numerical output of the boundaries of the data ranges for the two corresponding axes.

An example scatter-plot view is shown on the right side of Fig.1. It visualizes the data distribution of the data items according to two attributes. Clustered regions, but also outliers and trends are easily identified by using this view. Two-dimensional brushing of the data items in the scatter-plot is accomplished by interactively defining a rectangle (with the mouse) and thus creating a binary selection (see Fig.2(a)). To increase flexibility in brushing the data, multiple brushing regions can be defined (see Fig.2(b)), allowing to put distinct data clusters or subsets into focus simultaneously. Future work will include logical combinations of different brushing regions.

As already explained, smooth brushing was the concept of coping with the specialities of data from flow simulation. The boundary region of non-zero DOI values is visualized by a second rectangle enclosing the initial (binary) brushing region. This second rectangle can also be changed interactively, providing the possibility to separately define the region of interpolation of DOI values between 0 (context) and 1 (full focus) for each of the four directions. The DOI value is also encoded in the color of the points representing the data items in the scatter-plot.

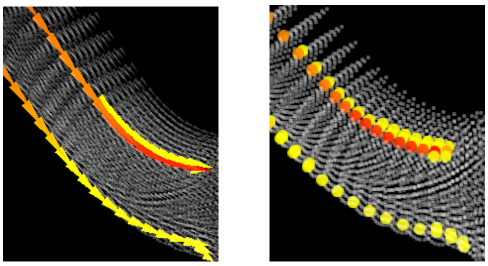
The histogram view (see Fig.5, for example) visualizes the number of occurences per (range of) data item(s) for one attribute, in contrast to the scatter-plot where only the data distribution and not the count is visible. In our approach it is linked to one of the axes of the scatter-plot and thus provides, at the same time, additionally data count information to the distribution information shown. Brushing mechanisms are similar to the scatter-plot, but obviously only 1D.

The histogram view also provides the user with a feedback visualization (color and opacity values) of the two transfer functions



(a) (b)

Figure 2: binary brushing of a cluster (a) and multiple brushing regions (b) in the scatter-plot



(a) (b)

Figure 3: 3D arrows (a) vs. 3D blobs (b), showing vortex core lines for the inlet of the catalytic converter application

employed in the 3D rendering view.

In the 3D rendering view (Fig.1 left side) currently two different rendering modes are available. *3D arrows* (Fig.3(a)) vs. *3D blobs* (Fig.3(b)) for every cell of the grid. The arrows are tetrahedron-like (length and orientation encode magnitude and direction of the flow at the current grid position), the blobs' geometry is a sphere. Opacity and color of the primitives are triggered by the transfer function as explained earlier.

Although volume rendering is currently being developed, the 3D arrows and blobs have the important advantage of giving a one-to-one representation of single elements in the data set, often asked for by special tasks of interest. For both modes the transfer function maps one attribute, in Fig.3 this is magnitude of the turbulence kinetic energy. 3D arrows provide the possibility of conveying additional information, such as direction and magnitude of the flow – that is only reasonable, if detailed information is desired about small regions of the data. When showing an overview, the advantages of the (then too) small arrows get lost, and rendering blobs is the better choice (keeping complexity lower, too).

All the available views are linked via the (non-discrete) DOI function defined in one of the InfoViz views by brushing the data. This DOI function is especially used to modulate the appearance of the 3D rendering for the data elements. Optionally opacity, color, and/or size of geometric objects can be modulated, depending on the F+C discrimination defined by the DOI value.

In the current setup of the prototype, also the attribute to axis mapping of the histogram axis and one of the scatter-plot axes are linked, as mentioned above.

Another feature of the prototype is that the brushing information (DOI function) persists until the next brushing interaction in any of the InfoViz views is performed. This allows to compare different attributes in the 3D rendering view for the same features. Also, analyzing and comparing data distributions in the scatter-plot by changing the attribute to axis mapping with the same DOI feedback visualization per data item is enabled through this concept. The next section discusses an example of this feature.

5 Results and Implementation

In Fig.4(a) the application of joining two flows (from left and upper pipes) into one (going to the right side) in a so-called T-junction is shown. Fig.4(b) shows the corresponding scatter-plot to Fig.4(a). A low velocity/low pressure area has been brushed smoothly, to focus on the recirculation area of the mixing flows. In the lower two images the currently active attribute to be visualized by the transfer functions in the 3D view and the currently active attribute to axis mapping for the y-axis in the corresponding scatter-plot view was changed to be the turbulence kinetic energy instead of the velocity. Note the persistence of the DOI function as described above.

Fig.5 presents a different example, coming from a simulation of the ventilation system in a car. This time, only a 2D slice of cells from front to back of the car was considered during simulation. The inlet of the ventilation system is the red region on the left side, where maximum velocity can be observed. The data has been brushed in a histogram view on velocity values, shown on the right side. Relatively high velocity values have been brushed smoothly, to specify the DOI function. Again the transfer function of the features in the 3D view is a colored one, red defining highest velocity values and green being associated with relatively small values (which are not in focus and thus not visible here). The context transfer function is a gray-scale one, and the size of the arrows used for the representation of the data elements is also smaller, nearly not visible. Linear interpolation of the alpha and color values, as well as of the size of the arrows is applied according to the DOI values.

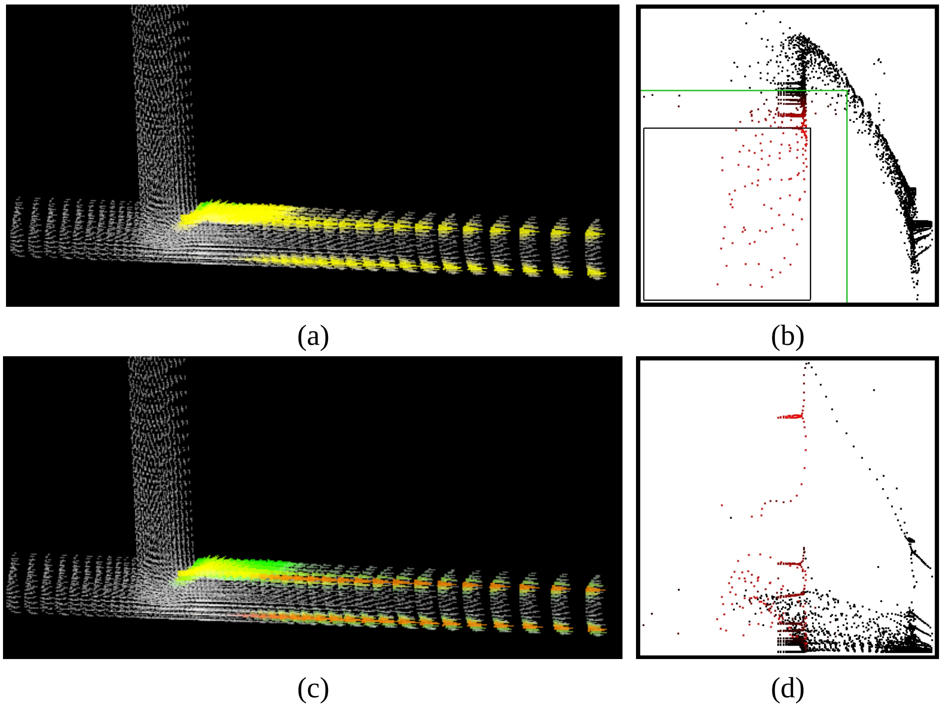


Figure 4: Smooth brushing of the recirculation area in a T-Junction application (a) and (b), changing of the attribute to axis mapping and attribute to transfer function mapping to turbolence kinetic energy on the previously brushed information (c) and (d)

Further results and video-sequences of working with the system are available at www.VRVis.at/vis/research/smooth-brush/.

The presented system has been implemented in a self-developed environment for visualization, called OFVis (Open Framework for Visualization). It is a combination of Java (for graphical UI) and C++ (for data access via libraries of our primary partner company AVL List GmbH), using Open GL for the rendering parts (using the *gl4Java* package). This allows for flexible data access, and possible extensions by using only data access routines that are different for other data sources.

The prototype system presented runs interactively on a standard PC platform (P3, 733MHz, 756MB, GeForce2) for the data sets shown (in the range of 20.000 to 60.000 cells, 15 to 40 data attributes associated to each cell). The cells of the data are organized in unstructured grids. For the rendering of these grids a visibility algorithm was implemented, based on the XMPVO algorithm [13] presented by Silva et al.

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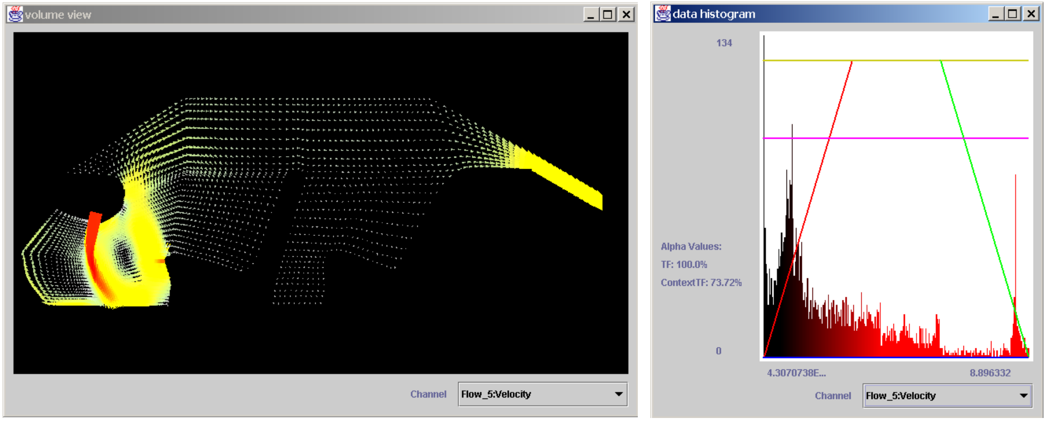

Figure 5: Smooth brushing in the histogram view (right) and linking to the 3D view (left): a 2D slice of the simulation of a car ventilation system, high velocity in focus.

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