Angular Brushing of Extended Parallel Coordinates

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Abstract

In this paper we present angular brushing *for parallel coordinates (PC) as a new approach to highlighting rational data-properties, i.e., features which – in a non-separable way – depend on two data dimensions. We also demonstrate* smooth brushing *as an intuitive tool for specifying non-binary degree-of-interest functions (for focus+context visualization). We also briefly describe our implementation as well as its application to the visualization of CFD data.*

Keywords: *information visualization, parallel coordinates, brushing, linear correlations, focus+context visualization*

1. Introduction

For many years now, parallel coordinates (PC) [6, 5] have been well-known and an often used technique in information visualization (InfoViz). Multi-dimensional data-sets are visualized by drawing one poly-line for every data-point across coordinate axes which are laid out in parallel, side-by-side. The poly-lines intersect the coordinate axes at points which correspond to the respective components of the particular data-vector. Thereby, up to a dozen data dimensions (or even more) are well visualized, especially when the visualization is combined with proper interaction features such as real-time re-ordering of coordinate axes or interactive brushing in single dimensions [8].

Brushing is a very effective technique for specifying an explicit focus during information visualization [1, 10]. The user actively marks sub-sets of the data-set, for example, by using a brush-like interface element. If used in conjunction with multiple linked views, brushing can enable users to understand correlations across multiple dimensions [1, 4].

Focus+context visualization. Brushing also is very useful to steer a drill-down into the visualization of really big data-sets – by specifying a (limited and limiting) focus, more details can be shown for the selected data-points. This relates to another very important InfoViz concept which is focus-plus-context (F+C) visualization [3]. The basic idea of F+C visualization is to jointly visualize highly interesting parts of the data in detail as well as the rest of the data-set in reduced style, for orientation and improved navigation.

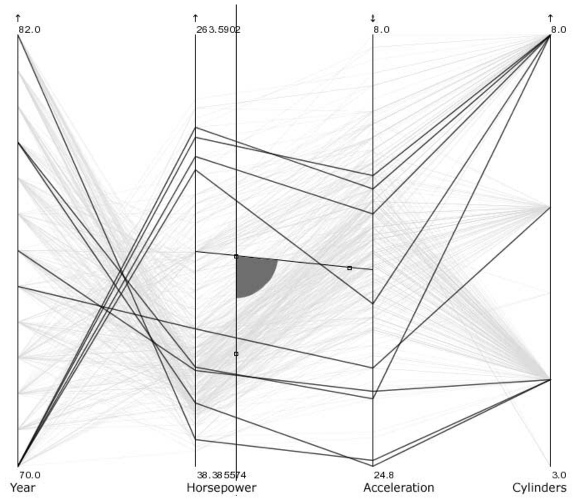

Figure 1. Reading between the lines: whereas most of the poly-lines have a pos. slope between the 2nd and the 3rd axis, just a few don't – those have been emphasized using angular brushing.

Degree-of-interest functions. For specifying which parts of the data are to be drawn in detail, i.e., for specifying the focus, a degree-of-interest (DOI) function is used [3], usually assigning a value of 1 or 0 to each data-point, depending on whether the data-point is of current interest or not. Brushing is an effective method to actively (and explicitly) assign values of 1 to data-points of interest [1, 11].

Brushing extensions. In addition to standard brushing, several useful extensions have been proposed in literature. The introduction of composite brushes [8], for example, enabled users to more specifically define their focus. The combination of brushing and non-binary DOI functions [8] proved to be useful for data-sets with gradual changes in their data attributes, for example, data from scientific simulation [2].

In this paper, we demonstrate *angular brushing* and *smooth brushing* as two effective extensions to interactive brushing of parallel coordinates (Sect. 2). Afterwards, we briefly present some implementation issues (Sect. 3). The

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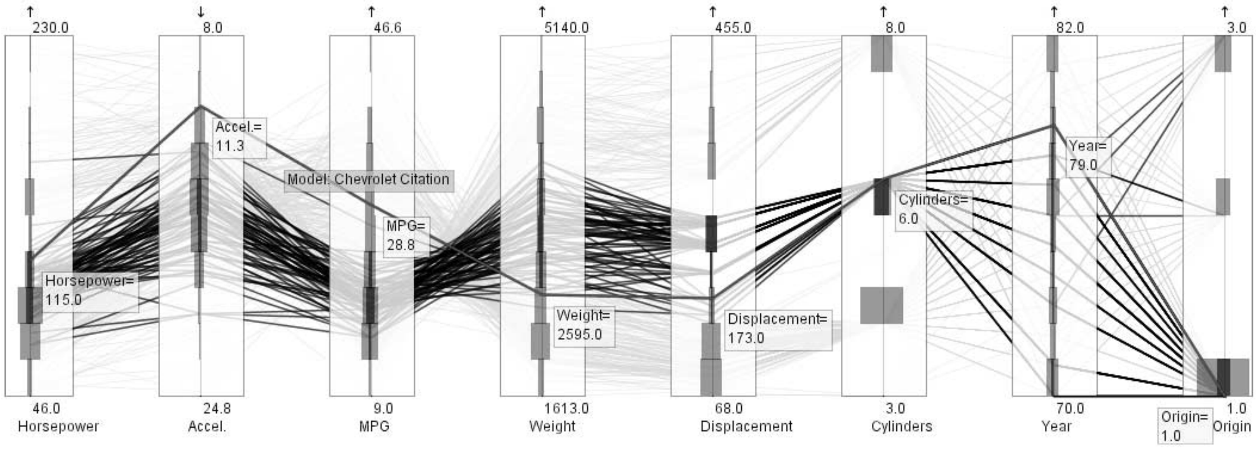

Figure 2. Extended parallel coordinates, a sample view of the *cars* data-set: cars with six cylinders were emphasized through brushing, histograms are laid over axes, and one data-point is shown with all details.

application itself and some results from visual data analysis are demonstrated in Sect. 4. A longer paper, describing more extensions of our prototype like composite brushes, histogram-overlays per axis, a very flexible axis-layout, a detail-on-demand feature, etc., is available from VRVis as a technical report (`http://www.VRVis.at/vis/`).

2. Extended Brushing for Parallel Coordinates

Brushing effectively enables the user to (explicitely) specify his or her focus. In parallel coordinates, this usually is accomplished by marking a certain data sub-set of interest according to values within a single data dimension. In the *cars* data-set [9], for example, a user could focus on cars with six cylinders by brushing the respective portion of the *cylinders*-axis (cf. Fig. 2).

In our application of visually investigating multi-dimensional data-sets originating in a physically-based simulation of dynamic processes based on computational fluid dynamics (CFD), we found standard brushing of PC very useful, however, we needed to go further. The requirement was to specify a focus not only in dependence of one data attribute (one dimension), but to do so with respect to at least two of them – like brushing all those data-points whose z-velocity is larger than the respective x-velocity. The consequence was to introduce a new brushing technique which we call *angular brushing*.

2.1. Angular Brushing of Parallel Coordinates

One strength of PC is its effectiveness of visualizing relations between coordinate axes. Bringing axes next to each other in an interactive way, the user can investigate how values are related to each other with special respect to two of the data dimensions. This way, it is not only possible to see whether data-points exhibit high or low values in single dimensions, but also their relation can be understood. More specifically, the slope of the line-segments between two axes tells the user, whether there is a positive or negative correlation between values (of course assuming that the user set up a proper visualization mapping). Outliers also can be easily found with respect to two data dimensions – when all but a few line-segments have a positive slope, then the few others clearly stand out (see Fig. 1).

In this paper, we demonstrate how this feature of PC easily can be exploited for an extended brushing technique, i.e., angular brushing. In addition to standard brushing, which primarily acts along the (parallel) axes, we enable the space between axes for brushing interaction, as well. The user can interactively specify a sub-set of slopes which then yields all those data-points to be marked as part of the current focus. See Fig. 1 for an example, where negative slopes have been marked between the second and third axis.

Angular brushing as described above is a useful extension to PC, also because it very well corresponds to the effective visual cues provided by PC. In addition to composite brushes which are composed multiple single-axis brushes by the use of logical operators, angular brushes allow the selection of (non-separable) rational properties with respect to two of the data dimensions. When compared to composite brushes by the use of a scatterplot visualization (see Fig. 3), we clearly see that brushes based on logical operators select sub-sets which are aligned with the display axes, whereas angular brushes select sub-sets which are aligned with the diagonals when visualized in a scatter-plot.

2.2. Smooth Brushing and Non-Binary DOIs

Many well-known F+C techniques in InfoViz such as fish-eye views [3], for example, do not use a discrete distinc-

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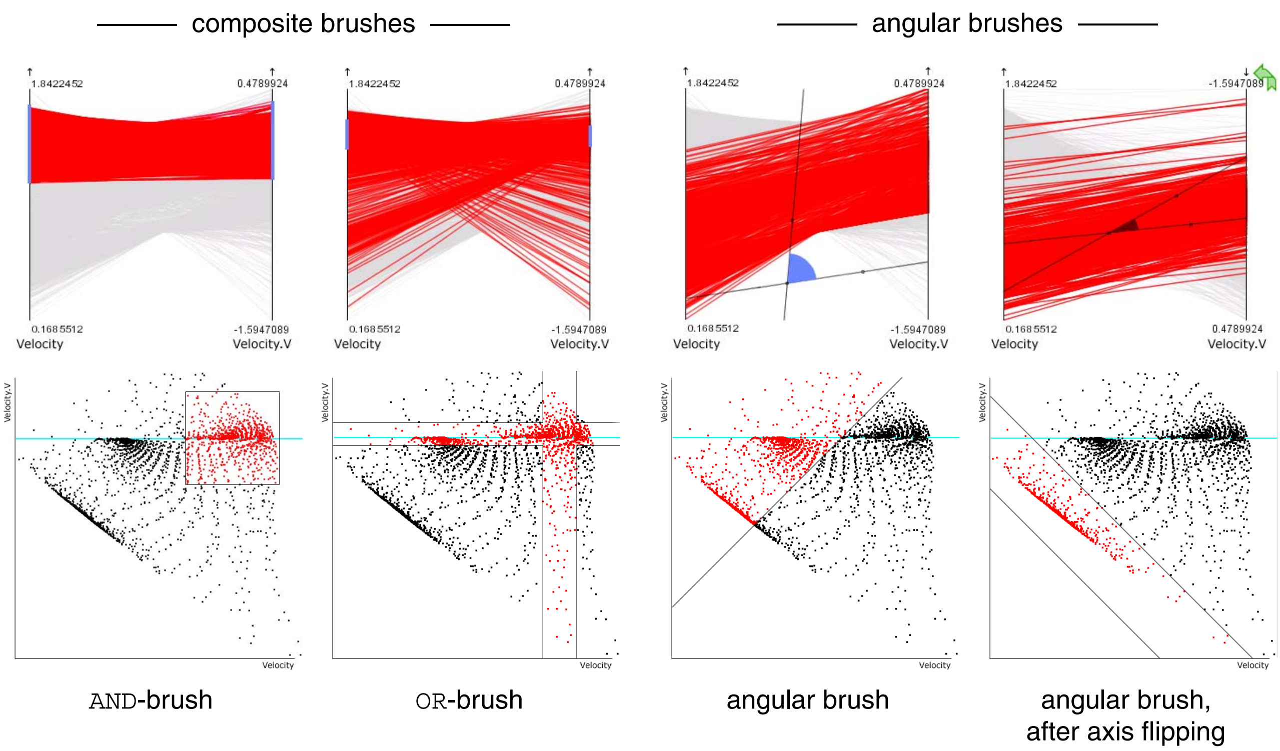

Figure 3. Comparing composite brushes (on the left) and angular brushes (on the right), using PC (top row) and scatterplots (bottom row): composite brushes address "horizontal/vertical" features, whereas angular brushes emphasize "diagonal" ones.

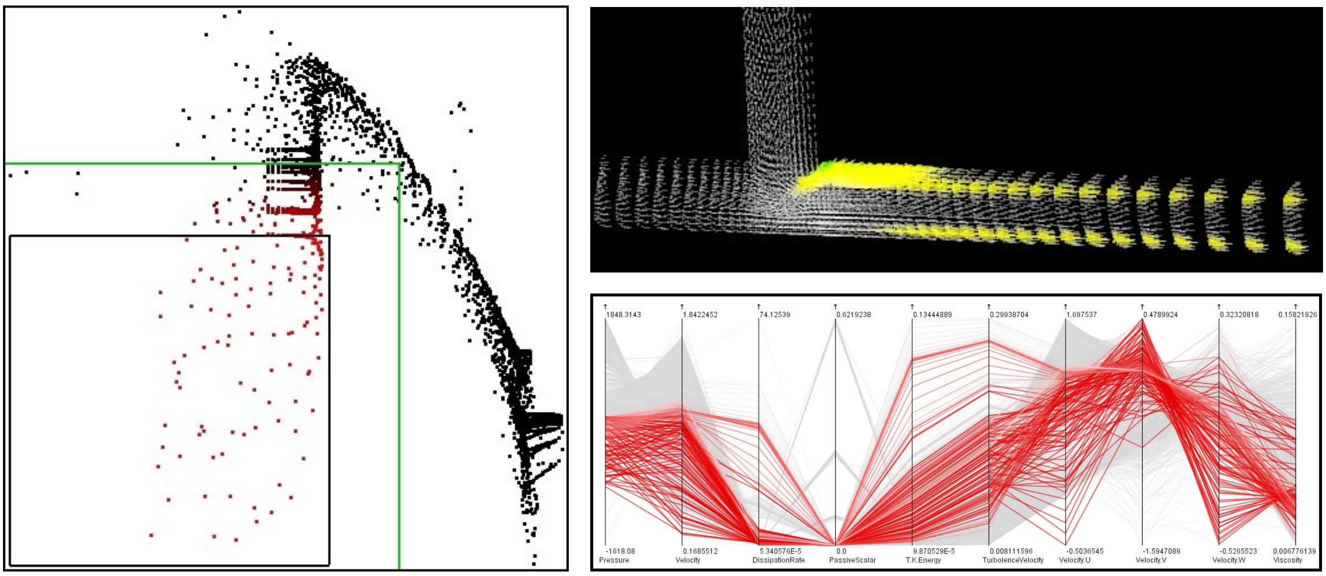

Figure 4. Linking and brushing, an example: in a scatter-plot (shown on the left side), smooth brushing was used to mark data-points of low pressure and low velocity; a linked 3D view (on the top right) shows the same data with the brushed data-points high-lighted; thirdly, the PC view (on the lower right) also shows the same data, also high-lighting the brushed sub-set.

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tion between focus and context, but allow a multi-valued or even continuous transition, which inherently supports the mental connection between data-points in focus and their context. This corresponds to a degree-of-interest function, which non-binarily maps into the $[0, 1]$-range.

Brushing easily combines with non-binary DOI functions [8], i.e., when using smoothly delimited brushes [2]. Thereby, at the brush boundaries, fractional DOI-values are assigned. When composite brushes are composed through the use of logical operators, fuzzy logic is employed to aggregate final DOI-values for every single data-point.

In conjunction with PC we extend the interactively specified brush by a certain, user-defined percentage to accommodate a smooth gradient of DOI-values at its borders. When combining smooth brushes through logical operators, we apply the Łukasiewicz norm, known from fuzzy logic as a comparably large norm [7], i.e., a norm which (when applied repeatedly) only slowly converges to 0 and therefore better conserves the transitional DOI-gradients.

3. Implementation

To deal with real-world data-sets – in our case consisting of 10^4–10^6 data-points each – we quickly experienced the limitations of a brute-force implementation of parallel coordinates. Especially as we also needed semi-transparency, coloring, and anti-aliased line-segments, load is high on the graphics hardware during PC visualization.

In the following, we briefly describe some of the approaches we utilized to still provide real-time response: (1.) Coherence is exploited during interaction by re-using as much visual output as possible. If one axis is modified during interaction, for example, line-segments are only redrawn locally. (2.) Progressive rendering provides immediate feedback through a preview-style of rendering, i.e., without anti-aliasing or semi-transparency. As soon as there is time, high-quality results are computed. (3.) Bi-threaded implementation de-couples rendering and interaction. One thread serves the user interface and guarantees interactive response, while the other thread deals with rendering.

4. Application and Results

In our application, we investigate multi-dimensional data-sets which originate in CFD simulations with a dozen of data dimensions, or more. During flow simulation, values like temperature, pressure, velocity, as well as others, are computed for all cells within a detailed CFD grid.

Parallel coordinates proved to be very useful for data investigation. The interactive character of our implementation allows for fast and flexible data exploration, even when simultaneously investigating multiple dimensions. Linking PC and other types of views (like a 3D SciViz view, cf. Fig. 4, top right) and using our brushing features eased data exploration. Also the combination with scatter-plots was found to be useful, primarily because 2D-composite brushes are specified more easily in a scatter-plot.

Figs. 3 and especially 4 show results of data exploration by the use of PC. The data shown is the result of a simulation of flow through pipes shaped as a T-junction. Flow is coming from the left and the top (Fig. 4, top left).

5. Summary and Conclusions

In this paper, we have presented *angular brushing* as a new technique to effectively select data sub-sets which exhibit a data correlation along two axes. We also showed how *smooth brushing* can be used, even in combination with *composite brushes*. More details, more images, a short video, as well as a longer technical report are available via `http://www.VRVis.at/vis/`.

We conclude that the worth of a visualization by the use of parallel coordinates increases drastically when interaction features like axis re-ordering, etc., are added.

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