

Additional On-Demand Dimension for Data Visualization

Natalie Hube¹, Mathias Müller¹ and Rainer Groh¹

¹ Chair of Media Design, Technische Universität Dresden, 01062 Dresden

Abstract

In this paper, we present a concept to interactively extend an 2d visualization by an additional on-demand dimension. We use categorical data in a multidimensional information space applied in a travel search scenario. Parallel sets are used as the basis for the visualization concept, since this is particularly suitable for the visualization of categorical data. The on-demand dimension expands the vertical axis of a parallel coordinate graph into depth axis and is intended to increase comparability of path variables with respect to the number of elements belonging to the respective parameter axis instead of direct comparability of individual paths and keep relations between the parallel sets. The presented implementation suits as foundation for further studies about the usefulness of a dynamic, on demand extension a of 2d visualizations into spatial visualizations. Furthermore, we present some additional approaches about the usage of the increased visualization space.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Computer Graphics]: User Interfaces—Graphical user interfaces

1. Introduction

Human perception is particularly focused on images, since visual representations can communicate information faster and more effectively than text. In contrast to scientific visualization, interactive information visualization aims to transform abstract information into an easily understandable visual form, instead of accurately representing spatial and object structures. Interaction plays an important role in the exploration of large information spaces, especially in regard to multidimensional visualizations.

In this paper, we present a concept to extend a classical 2d visualization with specific 3d features accessible on demand to visualize additional information. We examine the resulting consequences of the additional representation dimension and discuss future directions and enhancements of the concept. The travel search is used as an exemplary use case.

2. Related Work

In order to get an overview of techniques for the visualization of multidimensional data, approaches focusing on 2d text and image-based visualizations are contemplated. Additionally, the visualization of search results with regard to comparability of parameters is then examined.

2.1. Text-based visualization

Despite advances in search engine technologies, it can be argued that the common forms to present search results often don't meet

the users requirements, especially regarding customization and displaying relations. An example for the transformation of text-based search results into a graphical image is NIVRE [SCL*99]. An evaluation showed that the usability of a visualization technique correlates with the ability to reduce the user's mental workload as well as the users experience significantly affects performance with 3d applications. Best performance is achieved when traits of the tool match the tasks requirements. Thus, with the appropriate composition of task, user and interface, 3d visualizations are equivalent or superior to 2d or text-based visualizations.

[WF96] identified in a quantitative assessment that users performed significantly better in a 3d than in a 2d environment. As the 3d visualization allowed to move and rotate the visualization whereas the 2d visualization offered no such interaction, it can be deduced that interaction is the key to powerful 3d visualizations. In an evaluation by [Kos04], subjects performed better in a 2d than text-based information retrieval system when creating subsets of items and suggest to be used by expert users. However, [CVW09] argues that text may act as an introduction point for further exploration and suggests coordinated views to support analysis.

2.2. Image-based visualization

Interactive visualizations offer the opportunity of navigation in information spaces. [SAB13] analysed the visual search performance of 3d interactive storyboards in comparison to their 2d counterparts in terms of time-sensitivity and subjective evaluation. Although the 3d visualizations generally did not always improve performance,

they were still preferred by users as of a certain entertainment factor. Furthermore, [GRPF16] found that 3d can be a natural extension for disclosing relationships in 2d parallel coordinates.

[CM01] investigated the effects of 2d and 3d interfaces in a series of empirical studies. They found no significant differences between the 2d and 3d interfaces, but a subjective preference for 3d interfaces. In a second study they considered the reality factor as well as dimensionality [CM02]. The dimensionality was determined as the main influencing factor, as it took longer to retrieve web pages from interfaces with higher dimensions and decreasing performance. Hence, it is not enough to present an interface with an additional representation nor action dimension without taking into account additional functionalities to grant the user more control over the interface.

2.3. Visualization of Search Results

Regarding visual search, parallel coordinates [Ins09] are a feasible visualization technique for data exploration, as they support both object and attribute visibility. The use of parallel coordinates is often restricted to the academic field [ROF12], although it is a simple way to visualize multidimensional data. Problems often arise from text-based search interfaces. The user cannot see all objects at a glance or estimate the total number of objects presented. Hence, [ROF12] developed the Product Explorer, a tool for the selection of objects in an online store using interactive parallel coordinates. The authors dealt with the exact representation of attribute axes as well as depicted polylines and optimized interaction to include boundary regions to find quantitative distributions and relationships between closely adjacent axes. [FCI05] and [JFC14] have investigated parallel coordinates showing 2d relationships in a 3d visualization.

The work of [KHB*14] also deals with the Faceted Search to improve the product search with parallel coordinates. The presented interface concepts should increase the comprehensibility for untrained users. In addition to visualizations using parallel coordinates, they also discussed visualizations with parallel sets. Based on this, [KHH*14] used different search paradigms in their work and specified them more precisely. Further they propose to use structured and context-based data to improve the search experience and quality as the knowledge of the search domain is important and should meet the user's expectations. Their approach is using parallel coordinates combined with the work of [ROF12]. Moreover, they propose to use parallel sets as an analytical approach of information search instead of solely using parallel coordinates and supporting the four main interaction tasks of the visual information-seeking mantra [Shn96].

Therefore, advantages are only measurable in particular cases due to problems caused by occlusion or perspectivity. Thus, it can be stated that 3d visualizations aren't universally applicable as there is no recommendation to use 3d over 2d over text, as it depends on case-by-case which type of system could be best. Moreover, 2d visualizations have advantages in terms of clarity and legibility. In order to exploit advantages of spatial representations, the concept of a third dimension as an on-demand dimension is proposed. For the visualization of search results, it is of importance that the context of the search domain is related to the target group to ensure benefits

of the visualization. The use of parallel sets seems promising for the visualization of search results with faceted search techniques for inexperienced users as it reduces visual clustering [KBH06].

3. On-Demand Dimension Visualization Concept

Here, it should be noted that the 2d visualization is not replaced, but enriched by the third dimension in terms of an additional on-demand dimension. In the proposed use case for our application users follow different search paradigms, which are based to a greater or less detailed notion of the result [KHH*14] describe this type of search as a motive-based search. Therefore, a motive and the purpose of the action must first be defined in order to find a suitable result set. They denote the motive as a reason for the search as well as the specification of certain search criteria and the influence of emotional factors

The hardware setup for the concept consists of a common tablet for sensor-based tracking. At this point, the tilting and rotation of the tablet is used to track the location of the gyroscope and transfer it into motion used in the following concept. The virtual camera uses an orthographic projection.

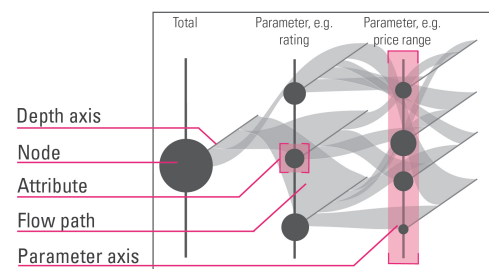


Figure 1: Terminology of the visualization shown in its 3d state.

3.1. Terminology

Parallel sets were chosen as a visualization technique due to their capabilities regarding the representation of categorical multidimensional data and their potential to visualize faceted search as proposed by [KHH*14]. Their approach provides the basic concept for our application. Table 1 contains descriptions of the terminologies shown in Fig. 1. The visualization concept is not limited to the representation of a 2d visualization, but also includes a 3d visualization as an additional on-demand dimension. Therefore, both approaches are described separately, whereby some concepts can overlap within the visualization dimensions.

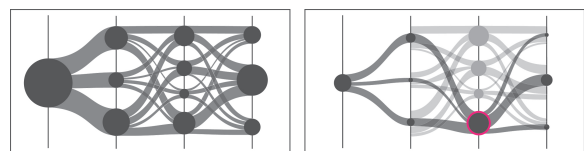


Figure 2: 2d visualization. Left: Initial state. Right: Selected node.

| Term | Description |
|----------------|---|
| Node | Nodes are located on the parameter axes on which the flow paths proceed. |
| Flow path | Flow paths are visual elements located between two nodes linking them. |
| Depth axis | Depth axes expand on the Y axis to map depth flow paths. Each depth axis resides at a node. |
| Attribute | An attribute represents a variable type and is a subgroup of a parameter axis. It consists of a quantitative, nominal, ordinal or categorical data. |
| Parameter axis | Parameter axes are vertical axes mapped on the X axis. Each parameter axis contains several nodes with the same attribute characteristics but different values. |

Table 1: Description of the visualization terminology

3.2. Parallel Sets in 2D

In a state-of-the-art study by [HW13] it was found that curved lines are easier to follow than straight lines. Despite a distortion of values, [Mou11] discovered that curved lines are more suitable for pattern perception. Hence, in its initial state, the visualization represents a 2d visualization using parallel sets (cf. Fig. 2). By using cubic Bézier curves, optical bundles are formed, which create white space in the region between the parameter axes. These symmetrical bundles produce a visually softer path and seem easier to follow. When a node is selected, it will be highlighted and the entire visualization is altered. Paths without elements from the selected node set receive a lower saturation (see Fig. 2). Additionally, other nodes adjust their size depending on the intersection of elements from selected nodes. In this case, a simple intersection operation is performed to find elements that are present in all nodes.

Considering clear traceability, the trend of paths can be perceived more quickly. Furthermore, the focussed node affects the entire information space and creates a more natural search for criteria. Since the entire information space is mapped within a single visualization, relations and dependencies between parameters can be identified more quickly. Additionally, the user has the opportunity to select several attributes simultaneously and is not dependent on the specification of exact and rigid criteria.

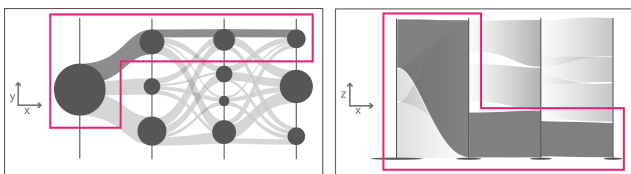


Figure 3: Left: Front view with X- and Y-axis. Right: Top view with Y- and Z-axis and representation of the unification of parameter axes. Marked areas of the left image correspond to the area of the right image.

3.3. Transition Animation

[HR07] and [YGX*09] reviewed the effectiveness of animated transition between different visualizations and found that anima-

tions can significantly improve visual perception and support visual search tasks. Furthermore, [EDF08] proposed using 3d animated transitions to support visual exploration of multidimensional data. Thereby, on demand, the 2d visualization can be altered into a 3d visualization by means of a transition animation. As on a 2d representation level, the interaction takes place in the actual world whilst shifting the device, in order to achieve a 2.5d visualization. This interaction modality is solely used to switch between the 2d and 3d visualization. The animation takes place in form of a continuously adaptive animation, which is divided into two steps (see Fig. 4) creating a natural transition from the 2d to the 3d state. First, paths are scaled down to a unified size, followed by the extension to 3d visualization. Thus, the depth axis expands.

3.4. Parallel Sets in 3D

The second part of the visualization is based on the representation of parallel sets in 3d space. As well as in the 2d visualization curved paths are applied due to their shape, since in 3d the width can be anticipated better than with straight paths. Nevertheless, when using curved paths the visual white space is not as strong in 3d as more overlaps and occlusions are created. Traceability of paths is of equal importance with the accessibility for the correlation of parameters and interrelations between the axes.

By expanding the entire information space on the depth axis, the information overview from selected nodes is improved. In the 2d visualization the paths overlap rather in the central area between two axes. In 3d, overlapping still occurs but no longer lies in the visual center of the visualization. Rather it's displaced by their spatial position and thereby shifting and scattering the occlusion of paths.

The expansion of nodes on depth axes also serves to unify paths. In this way, direct comparability of individual path variables is abandoned and a comparability of path variables with respect to the number of elements belonging to the respective parameter axis (see Fig. 3). For this purpose, the number of elements of a node is used as the total number for its parameter axis, and the corresponding width is adjusted to the depth for incoming and outgoing paths of the axis (see Fig. 6, left). Hence, paths are scaled according to their incoming and outgoing trails and a higher weighting of individual nodes is applied. This supports the comparability of parameter trails and volume ratios within sections of parameters.

3.5. Depth Stacking

As previously mentioned, aspects of the visualization concept can be applied to both dimensions. One is stacking path to avoid overplotting [NWA10]. Therefore, we identified two different sorting mechanisms which are more suitable for one dimension than for the other. The first variation arranges paths from top left to bottom right. The second variation arranges paths according to the distance of its two neighbouring nodes (see Fig. 5). This distance results from the position of a node on the Z axis in relation to an adjacent node (see Fig. 6, right). Both variation produce visually different visualizations and differ in terms of their advantages. As shown in Fig. 5 the top-down version seems more suitable for the 2d visualization whereas the next-neighbour principle is more convenient with the 3d visualization due to changes in overlapping paths.

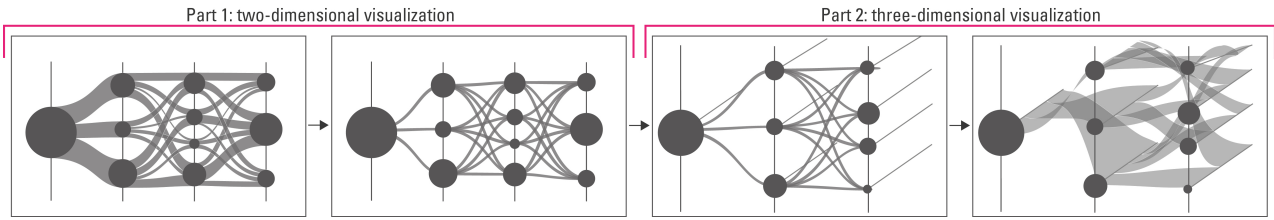


Figure 4: Transition animation. From left to right: Initial 2d view, 2d view with unfied paths, beginning of the transition into depth, and expanded 3d view.

3.6. Threshold Value Mapping

Another aspect is the mapping of a threshold value in relation to existing elements of a node, including a boundary area. The boundary area is created only if a node with ordinal or nominal data is selected and values from an adjacent node on the same parameter axis overlap at the threshold value. The threshold value is visualized as a slightly transparent surface above and below the actual path (cf. Fig. 6, center). The maximum size of this area depends on the number of elements it contains. Further, the position depends on whether elements in the threshold area lie above or below the selected value range. The mapping of threshold values are indicating other interesting information objects lying within the vicinity of the selected criteria. Concurrently, the quantity and position of the information objects located in this threshold value area are displayed visually. Though, slight deviations from the criterion are possible, as long as the overall selection becomes more demanding.

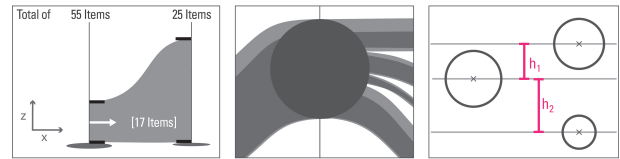


Figure 6: Left: Schematic representation of the unification of parameter axes. Center: Schematic representation of threshold value mapping. Right: Distance calculation between two nodes.

4. Conclusion & Future Work

The introduced concept presents an option to map the third dimension in form of an additional on-demand dimension in order to gain deeper insight into the information space and not to replace the 2d visualization but to enhance it. Categorical data is represented with parallel sets, thus further changes must be taken into account when changing the mapped data type to continuous data. Furthermore, there was an exemplary implementation of a prototype as a first proof-of-concept (cf. Fig. 7). The current implementation poses a framework to investigate the usability of the additional on-demand dimension. Further investigations must be made there.

In addition to the above-mentioned approaches of the motive-based search by [KHB*14], they also described an recommendation-based and similarity-based approach. This can be used in form of an additional on-demand dimension in order to depict correlations between price, rating and stars depending on axes in terms of travel search. Scalability with regard to the number of dimensions must be considered and examined farther.

Further modalities for filtering the information space can also be considered. A history-based approach to the depiction of a history in the demand dimension represents a possibility for the mapping and the comparison of a search history. At the same time, cutting planes on the depth axis offer a possibility to further filter the information space while supporting the recommendation-based and similarity-based search approach.

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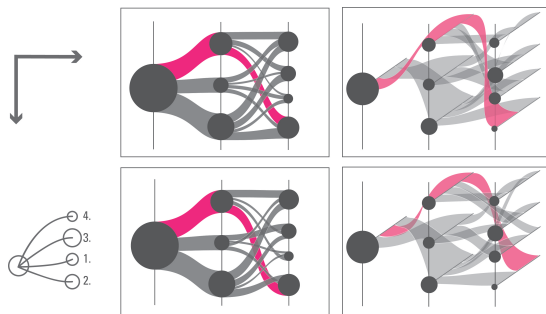


Figure 5: Illustration of the sorting modalities of paths. Row 1: Top-to-bottom sorting. Row 2: Next-neighbour-sorting.



Figure 7: Screenshot of the implementation.

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